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BLACKIE'S SCIENCE TEXT-BOOKS

ELEMENTARY PHYSIOLOGY

BY

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PREFACE.

This little work on Elementary Physiology is chiefly based on the notes of lectures given at various times—(*a*) to evening classes; (*b*) to extension students under the auspices of the Montgomeryshire County Council; (*c*) to students of elementary Physiological Psychology. Great pains have been taken to make it both accurate and lucid, and emphasis has been laid on Practical Work, to which a special chapter is devoted. The necessary Chemistry has been introduced where most relevant, instead of being lumped into an introductory chapter. Mr. A. W. Warrington, M.Sc., has kindly revised this portion for me.

The book is intended to meet the requirements of—(1) elementary students, whether self-taught or following the subject in class; (2) students of General Biology who wish to supplement that subject on the physiological side, as is often the case with those intending to go on to medical work; (3) students of Psychology who desire a simple account of the Nervous System and Sense Organs; (4) students of agriculture and dairying. The last chapter, which deals with secretion of milk and digestion in the cow, has been inserted in the hope that the last class of students may find it useful. Mr. J. Dawson Roberts, M.R.C.V.S., has been so good as to look over this chapter when it was in manuscript form.

J. R. AINSWORTH DAVIS.

ABERYSTWYTH, *August 1895.*

CONTENTS.

CHAP. Page
INTRODUCTION, ... 7
I. PRELIMINARY SKETCH, ... 8
II. SKELETON AND MUSCLES, ... 17
III. FOOD: DIGESTIVE ORGANS, ... 47
IV. DIGESTION AND ABSORPTION, ... 71
V. CIRCULATORY ORGANS AND CIRCULATION, . . . 80
VI. RESPIRATORY ORGANS AND RESPIRATION, . . . 101
VII. URINARY ORGANS AND THE EXCRETION OF NITROGENOUS WASTE, ... 114
VIII. THE SKIN AND ITS FUNCTIONS.—METABOLISM AND ANIMAL HEAT, ... 121
IX. THE NERVOUS SYSTEM AND ITS FUNCTIONS, . . . 127
X. THE SENSE ORGANS AND SENSATION, ... 143
XI. PRACTICAL WORK, ... 169
XII. DIGESTION IN THE OX AND COW—SECRETION OF MILK, . 191

ILLUSTRATIONS.

FIG. Page
1. Neural Tube with its contained Organs, - - - - 12
2. Dorsal and Ventral Tubes of Trunk, - - - - - 13
3. Chief Organs of Thorax and Abdomen, - - - - 16
4. Skeleton, - - - - - 21
5. Bones of the Skull, - - 23
6. Base of the Skull, - - 23
7. The Vertebral Column, - 27
8. A Thoracic Vertebra, - - 28
9. Top View of Atlas Vertebra, 29
10. Axis Vertebra, - - - - 29
11. Bones of Thorax, - - - 31
12. Model to illustrate Respiratory Movements, - - 32
13. Right Scapula, - - - 33
14. Right Humerus, - - - 34
15. Right Radius and Ulna, - 34
16. Bones of Left Hand, - - 35
17. Pelvic Bones, - - - 36
18. Bones of Right Leg, - - 37
19. Bones of Left Foot, - - 38
20. Bones of Right Foot, - - 39
21. Diagram of a Synovial Joint, 40
22. Biceps Muscle, - - - 42
23. Muscles and Tendons of Hand, 43
24. Lever of First Class, - - 43
25. ,, Second ,, - - 44
26. ,, Third ,, - - 44
27. Insertion of Calf-muscle, - 44
28. The Foot as a Lever of the Second Class, - - - 45

Fig. Page
29. Forearm as a Lever of the Third Class, - - - 45
30. Preparation of Oxygen, - 50
31. ,, Nitrogen, - 51
32. ,, Hydrogen, - 52
33. Alimentary Canal, - - 56
34. Section of Mouth, Nasal Cavities, &c., - - - 57
35. Jaws, with Teeth, - - 58
36. Kinds of Teeth, - - - 59
37. Section of a Tooth, - - 59
38. Stomach, &c., - - - 61
39. Alimentary Canal, - - 62
40. Section through Small Intestine, - - - - 63
41. Surface View of Villi, - - 64
42. Structure of Villus, - - 64
43. Structure of Stomach, - - 66
44. Stratified Epithelium (*Klein*), 67
45. Isolated Cells of Squamous Epithelium, - - - 67
46. Salivary Glands, - - - 68
47. Diagram of Gland Structure, 69
48. Stomach, Liver, Pancreas, and Spleen, - - - 70
49. Liver Cells, - - - - 70
50. Dialyzer, - - - - 76
51. Lacteals and Blood-vessels of Villi, - - - - - 77
52. Magnified Drop of Blood, - 82
53. Changes of Shape in White Blood-Corpuscle, - - 83
54. Organs of Thorax, - - 85
55. Diagram of Auricles and Ventricles, - - - - 86
56. Diagram of the Circulation,- 88
57. Exterior of Heart, - - 88
58. Left Side of Heart dissected, 88
59. Right ,, ,, - 88
60. Heart dissected from front, - 89
61. Structure of Capillaries, - 95
62. Structure of an Artery, - 95
63. Thoracic Duct and Lymphatics, - - - - 99
64. Lymphatics of Arm and Arm-pit, - - - - 100
65. Bronchial Tubes, - - - 103
66. Air-cells of Lung, - - - 104

Fig. Page
67. Cells of Ciliated Epithelium, 105
68. Preparation of Carbon Dioxide, - - - - - 109
69. Experiment to Compare Inspired and Expired Air, - 110
70. Preparation of Ammonia, - 116
71. Kidneys and Related Structures, - - - - - 117
72. Structure of Kidney, - - 118
73. Malpighian Body, - - 119
74. Part of Kidney Tubule, - 120
75. Structure of Skin, - - 122
76. Roots of a Spinal Nerve, - 128
77. Cross Section of Spinal Cord, 129
78. Muscle-nerve Preparation, 133
79. Diagram of Reflex Action, - 134
80. Median Longitudinal Section of Brain, - - - - 136
81. Upper Surface of Brain, - 137
82. Roots of Cranial Nerves, - 138
83. A Touch Corpuscle, - - 145
84. Section of Circumvallate Papilla, - - - - 148
85. Left Nasal Cavity, showing Nerves, - - - - 151
86. Propagation of a Pulse, - 152
87. Vibration of Straight Spring, 153
88. Diagrams of Auditory Organs (partly after *Schwalbe*), - 154
89. Auditory Ossicles, - - 155
90. Membranous Labyrinth, - 156
91. Bony Labyrinth, - - - 157
92. Section of Eye, - - - 158
93. Front half of Eyeball, - - 159
94. Back half of Eyeball, - - 160
95. Structure of Retina, - - 161
96. Formation of Image by Biconvex Lens, - - - 162
97. Formation of Image in Eye, 163
98. Diagram of Accommodation, 165
99. Diagram to show Blind Spot, 167
100. Leitz's Student's Microscope, 189
101. Crown of Grinder in Ox (after *Bos*), - - - - - - 192
102. Stomach of Sheep, - - 193
103. Milk and Colostrum, - - 200
104. Structure of Udder (after *Thanhoffer*), - - - 202

ELEMENTARY PHYSIOLOGY.

INTRODUCTION.

The globe is inhabited by an innumerable host of living beings, which may broadly be divided into plants on the one hand and animals on the other. There is so much in common between these that they are together treated of by a single science,—**Biology** (Gk. *biŏs*, life; *lŏgŏs*, discourse), which, however, covers such an enormous extent of ground that it is found convenient to subdivide it into the sister sciences of **Botany** (Gk. *bŏtanē*, a plant) and **Zoology** (Gk. *zōŏn*, a living creature; *lŏgŏs*), dealing respectively with plants and animals. There are two chief ways in which a living being may be studied, one having regard to the external shape and internal arrangement (*structure*) of parts, and the other going into the uses (*functions*) of the different parts or organs. These two methods of study are respectively adopted in the departments of **Morphology** (Gk. *mŏrphē*, shape; *lŏgŏs*) and **Physiology** (Gk. *phūsis*, nature; *lŏgŏs*). Botany embraces **Plant Morphology** and **Plant Physiology**, while Zoology includes **Animal Morphology** and **Animal Physiology**. We are here chiefly concerned with the last subject, and indeed with a branch of that subject, **Human Physiology**, or the physiology of man. It is, however, obvious that some knowledge of **Human Morphology** is also necessary for our purpose. It is not possible to understand how a machine—say a watch—acts, without possessing some knowledge of its construction, and before trying to understand the working of the human body it is necessary to have some acquaintance with its outward shape (**External Morpho-**

logy), internal structure or **Anatomy** (Gk. *ana*, up; *temnō*, I cut) as determined by ordinary dissection, and minute anatomy or **Histology** (Gk. *histŏs*, a texture; *lŏgŏs*) as made out by means of the compound microscope. The relation between these various branches of enquiry may be conveniently shown by means of the following table:—

- BIOLOGY.
  - Botany.
  - Zoology.
    - *Animal Morphology* (of which Human Morphology is a small part):—
      - *a.* External Morphology;
      - *b.* Anatomy;
      - *c.* Histology.
    - *Animal Physiology* (of which Human Physiology is a small part).

Even a beginner in Physiology will also have to know something of non-biological subjects, especially of Mechanics, Physics, and Chemistry. In this book the requisite knowledge of this kind will to some extent be introduced as occasion may arise.

In the study of Physiology bookwork alone is comparatively useless, and practical work of the greatest importance. As regards Human Anatomy elementary students will mainly depend on examination of the skeleton, supplemented perhaps by models of some of the soft parts; but fortunately the main points can be illustrated by dissection of a rabbit, cat, or dog—a sheep's pluck—and the eye of a sheep or ox. A small amount of microscopic work is also necessary for the beginner. For details see the Chapter on Practical Work.

CHAPTER I.

PRELIMINARY SKETCH.

Symmetry of the Body.—Objects which possess a certain regularity in form, enabling them to be divided into two corresponding halves in one or more different ways are said to be *symmetrical*. The most perfect kind of symmetry is seen in the sphere, which can be divided into two corresponding hemispheres in any direction, while the less symmetrical cube is divisible into equivalent halves in only nine different ways. Plants and animals, or their parts, commonly exhibit either **radial** or **bilateral symmetry**. The former is the kind of regularity observable in a star, wheel, or buttercup flower, where a number of exactly similar parts are arranged round a central point in a radiating manner. Any ordinary leaf, say one of ivy or violet, may be taken as an instance of a flat body showing **bilateral symmetry**, where, as the name implies (L. *bi-*, two; *latus, lateris*, side), there is only one possible way of dividing the object into two corresponding halves. Note further that these halves are not interchangeable like the two hemispheres into which a sphere can be split. They are in fact **right** and **left**, or, in other words, are **mirror images** of each other; for if the cut edge of one half be placed against a piece of looking-glass the reflection will look like the other half. The human body is also an example of bilateral symmetry, and this involves the possession not only of right and left sides but also of **front** or **ventral** (L. *venter*, belly), and **back** or **dorsal** (L. *dorsum*, back) surfaces, the two differing in shape from one another. It is also characteristic of Man, in common with all other bilaterally symmetrical animals, that there should be a **head end** lodging the brain and certain important organs of sense. Some animals, such, for example, as crayfish and lobster, are bilaterally symmetrical (or nearly so) as regards their internal structure as well as in external form, but in Man this is only the case to a limited extent.

Regions of the Body.—There is an obvious division into head, neck, trunk, and limbs or appendages. The **head** in Man, owing to the enormous size of his brain as compared with lower animals, is chiefly made up of the **brain-case**, which even forms the upper part of the **face**, the rest of which is constituted by the jaws, together with the parts related to the organs of sight and smell. At the sides of the head are the expansions known in ordinary language as 'ears', scientifically as **conchæ** (L. *concha*, shell), which largely surround orifices by which sounds enter to be conveyed to the essential organs of hearing, lodged deep down in the firm, bony side-walls of the brain-case and thus protected from injury.

It is obviously an advantage that the head, containing as it does important organs of sense bringing us into relation with the external world, should be borne upon a flexible, relatively narrow **neck**. This permits the eyes in particular to range very quickly over surrounding objects in nearly all directions without necessitating movement of the comparatively unwieldy trunk. A large expenditure of energy is thus saved and a change in the surroundings rapidly perceived, a matter of great importance even to civilized human beings, and to savages in many cases a matter of life or death.

The **trunk**, which lodges important organs concerned with nourishing the body and getting rid of its waste products, is divided into the **chest**, or **thorax**, above, and the **abdomen** below. The walls of the former are supported by bones in front and at the sides as well as behind, while the abdominal walls are soft and not so supported except behind.

Although there are considerable differences between the **upper** and **lower limbs**, owing to the fact that they are put to such different uses, there are nevertheless important agreements between them. They are, in fact, built upon a *common plan* of structure, and hence receive the common name of limb, appendage, or extremity, just as the term house is applied to cottage, villa, mansion, or any other dwelling. Upper and lower limb alike are transversely divided into certain regions, and end in five digits provided with flat nails. Thus shoulder, upper arm, forearm, wrist, and hand correspond to hip, thigh, leg, ankle, and foot. Shoulder and hip, although commonly reckoned as part of the trunk, belong more properly to the limbs, being in fact limb-regions, which are firmly fixed to the trunk and afford attachment to the free or movable parts of the limbs. Examination of a sheep's carcass, as displayed in a butcher's shop, or of a skinned rabbit, will show that this is true as regards the shoulder, but it is by no means obvious in the case of the hip-region, which has fused very closely with the trunk.

Differences between Upper and Lower Limbs.—Most of these can be considered with greater profit when the corresponding bones are studied, but a few points may be mentioned here. The upper limbs are especially adapted for grasping objects situated in very various directions, and in correspondence with this the shoulder-joint allows of very free movement, the forearm can be twisted round so as to bring the palm into several positions, the fingers are long and flexible, and the relatively short thumb can be opposed to the other digits, *i.e.* its tip can be brought against theirs. The lower limbs on the other hand have to support the weight of the body and bring about various kinds of locomotion. The hip-joints do not therefore allow of such free movement as do the shoulder-joints, the leg cannot be twisted round like the forearm, the toes are shorter and less flexible than the fingers, while the relatively long and large great toe cannot be opposed to the other toes. To this may be added the fact that the thigh and leg are much longer than the corresponding parts of the upper limb, and the heel, which is of great importance in the support of the body, has nothing in the hand corresponding to it.

The Trunk a Double Tube.—Both upper and lower limbs are solid, but the trunk is hollow, containing two cavities, one anterior or ventral and the other posterior or dorsal. In these cavities various internal organs are enclosed. The trunk may, therefore, be described as a double tube, and this arrangement can easily be made out by looking at the cut side of one of the longitudinal halves into which a butcher commonly divides the body of a sheep or pig. The **dorsal cavity**, which extends into the neck and head, contains the brain and spinal marrow, or spinal cord, and is almost entirely

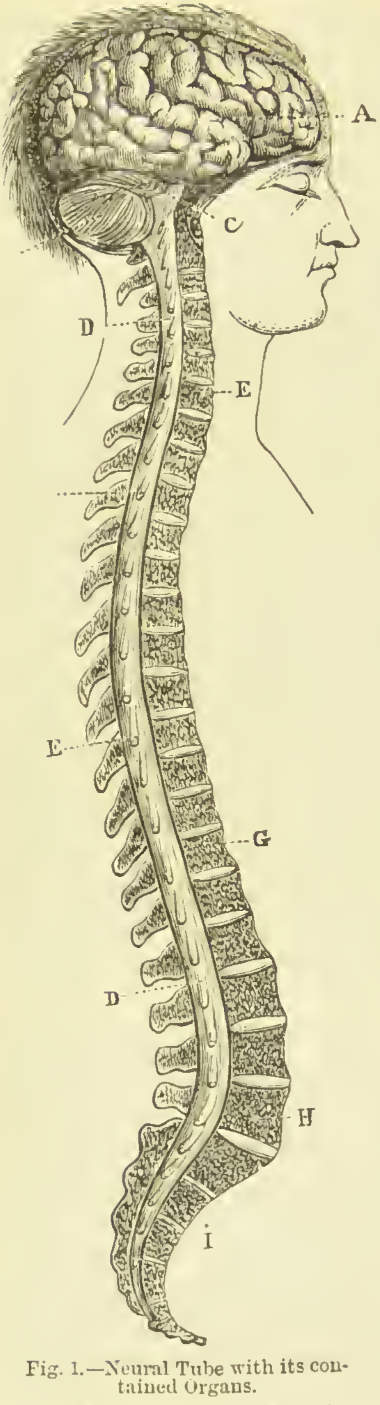

Fig. 1.—Neural Tube with its contained Organs.

A B C, Brain; D E E D, spinal cord; G H I, backbone.

bounded by bone, so that these delicate organs may be well protected. Fig. 1 shows this cavity and the organs which fill it, as seen in Man. In the neck and trunk it traverses the spine or vertebral column, and is comparatively small in correspondence with the size of the spinal cord which it contains. In the head, however, this cavity is very much larger, as it has to hold the brain. The **ventral** or **body cavity** is limited to the trunk, and is of relatively large size, as shown in fig. 2. It is not so well protected by bone as the dorsal cavity. On reference to the figure it will also be seen that the ventral cavity is divided into a smaller upper or **thoracic part** (A), and a larger lower or **abdominal part** (C), by means of a curved partition (B), the 'midriff' or **diaphragm** (Gk. *dia*, across; *phragmŏs*, a partition). When at rest this is convex above and concave below. It is pierced by various structures running from thorax to abdomen or the reverse. The head contains ventral cavities belonging to the nose, mouth, and throat (fig. 34), but these are not of the same nature as the body cavity.

General Sketch of the Functions and Organs of the Body.—The regions and general plan of the body have already been discussed from a morphological point of view, and it now remains to classify the various parts on a physiological basis, having regard, that is, to their uses or functions.

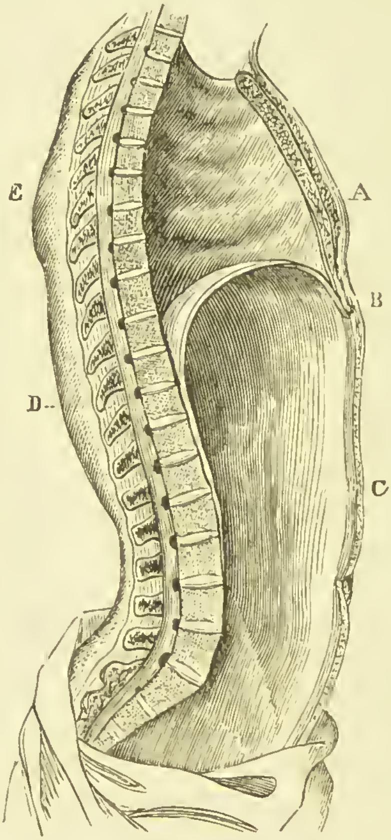

Fig. 2.—Dorsal and Ventral Tubes of Trunk.

In any kind of manufacture it is well known that the best results are obtained by dividing the work into different stages, undertaken by distinct sets of work-people who, as a result, become very expert at their particular duties. This principle of **division of labour,** as it is called, is carried out very perfectly in the human body, where we find special parts or **organs,** each of which performs one or more functions. These organs, eye, lung, brain, stomach, &c. &c., are more or less different from one another, since their shape and structure are such as to fit them for very different tasks. The body has gradually become thus **differentiated,** *i.e.* made up of differing parts, as a result of well-marked **division of physiological labour.** The various organs may conveniently be grouped under the following headings:—

1. **Protection and Support.**—The body is supported by bones and other hard parts together forming the **skeleton.** This also protects the more delicate organs from injury, as, for example, in the case of the brain and spinal cord (p. 12).

The **skin** is also an important protective organ, in virtue of its outer layer or **epidermis** (Gk. *ĕpi*, upon; *dĕrma*, skin), which is non-sensitive and devoid of blood-vessels. The hair and nails are special outgrowths from this layer. There is a great difference between the epidermis and the deeper part of the skin constituting the **dermis**, which is both sensitive and richly provided with blood-vessels. When the finger is cut with a knife no pain is felt nor blood drawn till the dermis is reached.

2. **Movement.**—The chief agents in producing the various movements of the body and its parts are the **muscles**, which in ordinary language are known as the 'flesh', or in dead animals as 'meat'. They are also the means by which the body is kept in the erect and other positions involving effort. A given muscle consists of a definite piece of fleshy substance which is able to **contract**, that is, to become shorter and at the same time broader. Its two ends and the parts to which they are attached will thus be brought nearer together. It must clearly be understood that this property of **contractility** is not the same thing as *contraction* in the ordinary sense of diminution in volume.

3. **Digestion.**—**Energy** is defined as the power of doing work, and a distinction is drawn between 'stored' or **potential energy** and 'actual' or **kinetic energy**. The various activities of the body necessitate a large expenditure of kinetic energy, and this involves a constant breaking down of body substance. A rough idea of the process may be gained by considering what takes place when nitro-glycerine explodes. The substance in question is of very complicated chemical nature, and its explosion means—(1) the re-arrangement of its constituents to form simpler substances; (2) the conversion of potential into kinetic energy, resulting in the performance of a certain amount of work. Similarly when a muscle contracts it does work, and at the same time a small part of it wastes, *i.e.* breaks down into simpler substances, with conversion of potential into kinetic energy. If this waste were not made up for, the muscle would

gradually get smaller and smaller with use, which, however, is not the case. **Food** is material taken into the body for the purpose of compensating waste and rendering growth possible where desirable. **Digestion** is the process by which this food is brought into a fit condition to be built up into living substance, and the **digestive organs** undertake this special work. They consist of a long tube, the **alimentary canal**, and of certain organs which open into it. This tube begins with the *mouth-cavity*, which is continued into a small chamber (*pharynx*) at the back of the throat, followed again by a tubular *gullet*, dilated *stomach*, and long convoluted *intestines*, or bowels, beginning with a relatively narrow *small intestine* and ending with a much broader *large intestine.* As may be seen from fig. 3, the abdominal cavity is largely occupied by the stomach and intestines together with the large **liver**, which is one of the important organs opening into the digestive tube.

4. **Circulation.**—Digestion would be a useless process if there were not some means of conveying the digested food throughout the body. This is one of the functions of the **circulatory organs**, which principally consist of the **heart** and **blood-vessels.** The former acts as a force-pump by means of which the **blood**, containing the products of digestion, is made to move through the blood-tubes or blood-vessels. In fig. 3 the heart is shown in its natural position in the middle of the thorax, and at its upper end are seen parts of the great blood-vessels which begin or end in it.

Besides carrying material for effecting renewal or growth to the different parts of the body, the circulatory organs remove the products of waste and take them to organs which get rid of them (lungs, skin, kidneys). Besides this, as will presently appear, the organs of circulation promote waste and equalize the temperature of the body.

5. **Respiration.**—This process, commonly termed **breathing**, involves the passage of air into and out of the **lungs**, two large spongy bodies which largely fill up

the thorax (fig. 3, B B), and communicate with the exterior by the tube known as the **windpipe** or **trachea**, which can readily be felt along the front of the throat, just within the skin. The purpose of breathing is twofold: (1) to **excrete** or get rid of certain **waste products** resulting from the constant wasting of living substance; (2) to **absorb** into the blood from the air **oxygen gas**, which enables the necessary energy-producing and heat-producing processes of waste to go on.

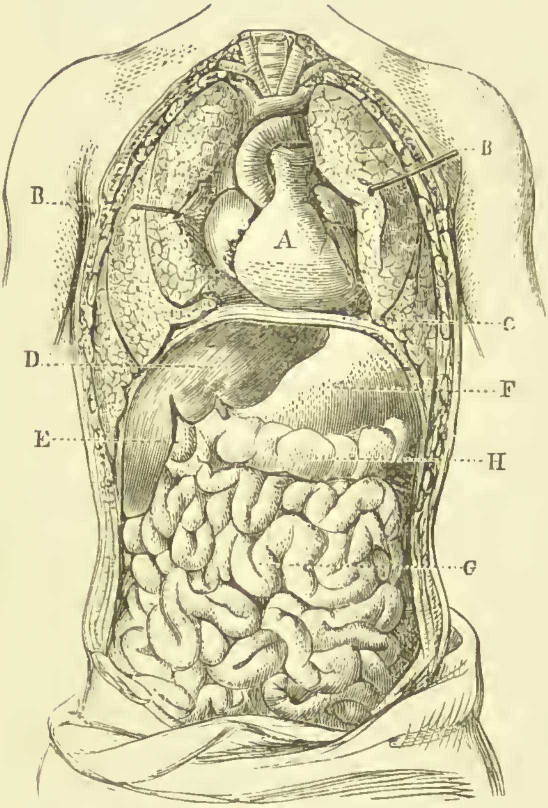

Fig. 3.—Chief Organs of Thorax.

A, Heart; B B, lungs; C, diaphragm; D, liver; E, gall-bladder; F, stomach; G, small intestine; H, part of large intestine.

6. **Excretion** (L. *ex*, out of; *cerno*, I separate) or elimination of waste from the system is a function of lungs, skin, and also of the **kidneys**, two flattened oval bodies lying at the back of the abdominal cavity (fig. 71), and communicating by two narrow tubes, the **ureters**, with a somewhat pear-shaped bag or sac situated at the lower end of the abdominal cavity and known as the **urinary bladder**.

7. **Correlation and Sensation.**—In order that the organs of the body may work properly together, it is necessary that there should be some apparatus for bringing them into relation with one another. The

nervous system is a correlating apparatus of this kind. It consists of **central organs** connected by slender cords, the **nerves**, with all parts of the body. The central organs consist of **brain**, **spinal cord**, and two slender **sympathetic cords** lying just at the sides of the backbone. The brain must be regarded as the master organ of the body. It is the seat of intelligence and will, and not only brings the various organs into relation with one another, but also, by means of its instruments, the **sense organs**, brings the body, so to speak, into touch with the external world. The sense organs include the structures which have to do with touch, taste, smell, hearing, and sight.

CHAPTER II.

SKELETON AND MUSCLES.

The Materials which make up the Skeleton. —The organs which compose the body can again be analysed into a comparatively small number of materials, just as the different parts of a house are built up of stone, mortar, wood, &c. These body materials are called **tissues**, and three of these tissues—bone, gristle or cartilage, and connective tissue—together build up the skeleton. A rabbit's leg may be taken in illustration. After removing the skin and muscle the **bones** will be reached, connected together at the joints by strong tough bands, the **ligaments** (L. *ligo*, I bind), made up of a kind of **connective tissue.** This tissue is called "connective" because it connects or binds the various organs and parts of organs together. Each bone is also covered, except where it helps to bound a joint, by a tough membrane, the **periosteum** (Gk. *pĕri*, around; *ŏsteŏn*, bone), made up of connective tissue and very vascular, *i.e.* richly supplied with blood-vessels. Select the femur (thigh-bone) for further examination. After dissecting it out, each end will be found covered by a thin smooth layer of firm bluish-white **gristle** or **cartilage** (L. *cartilago*, gristle), easily cut with a knife. On dividing the bone into two longitudinal halves it will be seen that the central part or shaft contains a large cavity bounded at the sides by very dense bone, and containing a soft fatty substance, the **marrow**, of a reddish colour. The swollen ends of the femur are made up of spongy bone, the minute interstices of which are filled up with marrow. It will also be noted that the cartilage covering each end of the bone is comparatively thick in the middle, gradually getting thinner, and being finally replaced by the periosteum. Marrow consists of a framework of connective tissue, and its red colour is due to the presence of minute blood-vessels, which have direct communication with those in the periosteum by means of a minute hole, the **nutritive foramen** (L. *foro*, I pierce), which pierces the middle of the shaft. There is also *indirect* connection, for the compact bone forming the wall of the shaft is traversed by minute canals (Haversian canals) running mainly in a longitudinal direction, and containing minute blood-vessels, which communicate by cross branches with the vessels of the periosteum on the one hand and those of the marrow on the other. The Haversian canals are large enough to be seen with a lens if the bone is broken across, and in the fresh state some of the cross branches can also be made out. It will thus be seen that a bone is not a mere mass of hard dead substance supporting the surrounding soft parts, but is pierced by an elaborate network of blood-vessels, from the blood contained in which the materials necessary for growth or repair of injury can be drawn.

General Composition of Bone.—If a rabbit's thigh-bone is soaked for a few days in dilute hydrochloric acid (muriatic acid) it will be found to have undergone a remarkable change in nature, whilst retaining the same shape. Instead of being hard and firm, it is now soft and flexible, capable of being tied up into a knot without breaking. The acid has, in fact, removed the earthy or **mineral matter**, which gives the bone its hardness, leaving behind the **animal matter**, which makes it tough and to some extent elastic. This animal matter, which is closely allied to connective tissue, can be removed from a bone by prolonged boiling, as in making soup, or by heating in the fire. It is now the mineral matter which is left, and while, as before, the bone retains its shape, it will have become extremely brittle.

In healthy human bone the mineral matter constitutes about two-thirds the weight, but it is generally held that there is a smaller proportion in children and a larger in old people, accounting for the fact that the bones in the one case are comparatively flexible, and in the latter more brittle and liable to break.

Physical Properties of Bone.—Its hardness, toughness, and elasticity have already been noted, but these are not merely due to its composition, but also to the way in which its parts are arranged. Thus, the elasticity of the long bones is very much increased by their curved shape, while in the shaft of such a bone as the femur lightness and strength are combined on the principle of the hollow column, with the least possible expenditure of material. Spongy bone illustrates the same kind of thing. Its structure necessarily makes it light, and the slender bars of bone which compose it are not arranged at random, but so as to resist to the best advantage the pressures which have to be borne. A cubic inch of spongy bone, weighing only 54 grains, cut from the lower end of a human femur, was found, in an experiment made for the purpose, to stand a weight of 4 cwt. without being injured. This kind of bone also plays an important part in breaking shocks. It may be added that compact bone is reckoned to be twice as strong as oak.

Properties of Cartilage.—Cartilage or gristle is closely allied to connective tissue. It is tough, but at the same time extremely elastic, and these properties render it very useful in joints, as will presently be shown. Like spongy bone it helps to prevent jolting, as, for example, in the backbone. Except when entering into joints, cartilage is covered by a vascular membrane, called in this case the perichondrium (Gk. *pĕri*, around; *chŏndrŏs*, cartilage).

GENERAL PLAN OF THE SKELETON.

The numerous bones which make up the skeleton may roughly be divided into three kinds—(1) **long** bones, such as the femur, which are used as levers; (2) broad **flat** bones, like those of the brain case, which protect delicate organs; and (3) short **irregular** bones, found in parts like the wrist and ankle, where both strength and capability for a limited amount of movement are requisite.

Axial and Appendicular Skeleton.—The bones of the head, neck, and trunk constitute the skeleton of the body, as distinguished from the limbs or appendages. They comprise the skull, backbone or vertebral column, ribs, and breast-bone or sternum. The last two support the top, sides, and front of the thorax, as will appear on reference to fig. 4. The bones of the limbs make up the appendicular skeleton, and just as the upper and lower limbs can be divided into corresponding regions (p. 10), so can their bones be grouped in a similar manner. In either case there are (1) bones constituting a **girdle** by which the limb is fixed to the trunk, and (2) bones supporting the fleshy movable part of the limb. The following table gives a more detailed comparison. (Cp. fig. 4.)

Upper Limb.	Lower Limb.
I. **Shoulder Girdle.**—A large flat **shoulder-blade** (scapula) behind and a rod-like **collar-bone** (clavicle) in front.	II. **Hip Girdle.**—A large, flat, irregular **hip-bone** (os innominatum).
II. **Free Limb.**	II. **Free Limb.**
1. **Upper-arm bone** (humerus).	1. **Thigh-bone** (femur).
2. Forearm bones—(*a*) **radius** on thumb side, (*b*) **ulna** on little finger side.	2. Lower leg bones—(*a*) **tibia** on great toe side, (*b*) **fibula** on little toe side.

[There is nothing in the upper limb to represent the small **knee-pan** (patella) on the front of the knee-joint.]

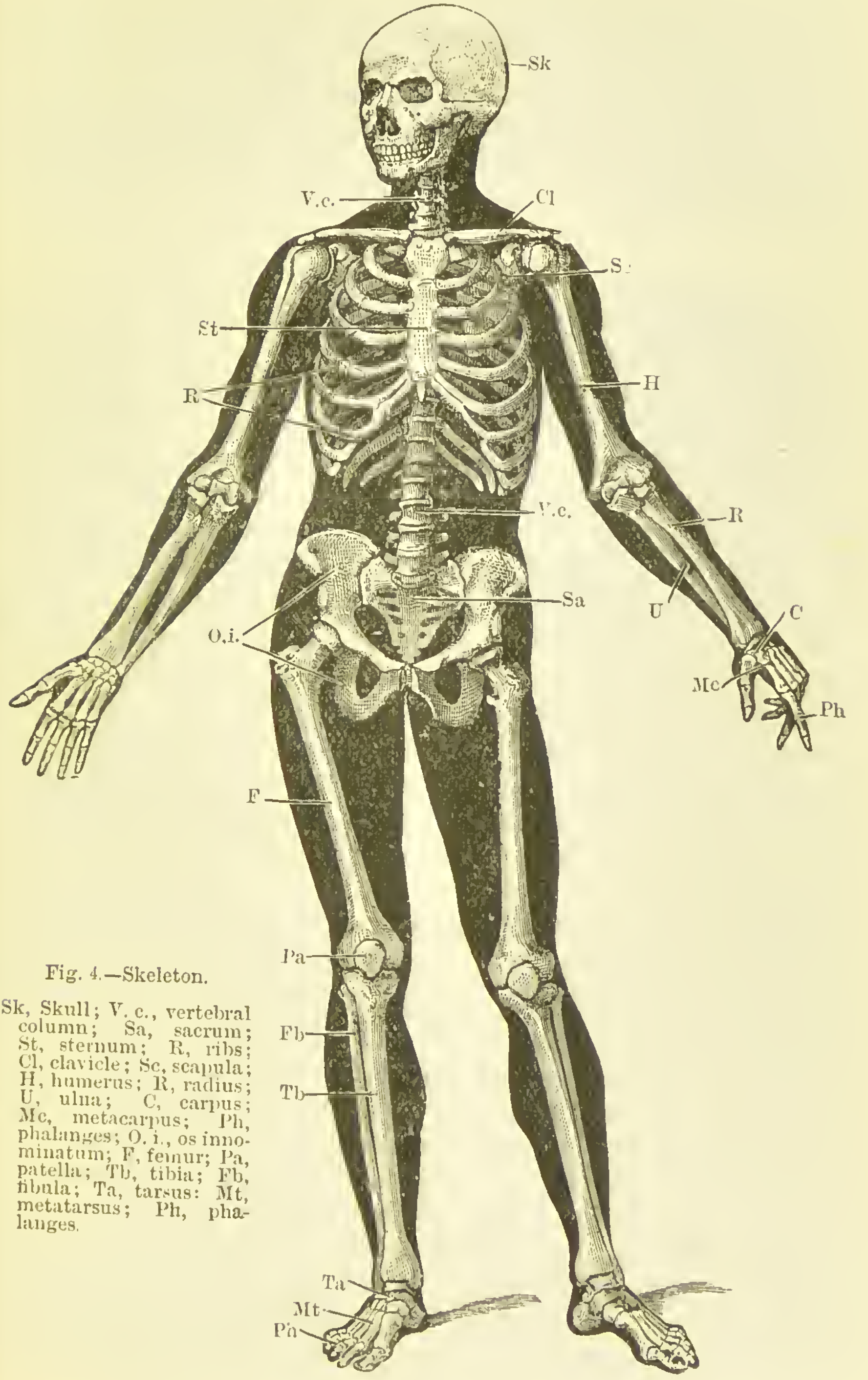

Fig. 4.—Skeleton.

Sk, Skull; V. c., vertebral column; Sa, sacrum; St, sternum; R, ribs; Cl, clavicle; Sc, scapula; H, humerus; R, radius; U, ulna; C, carpus; Mc, metacarpus; Ph, phalanges; O. i., os innominatum; F, femur; Pa, patella; Tb, tibia; Fb, fibula; Ta, tarsus: Mt, metatarsus; Ph, phalanges.

Upper Limb.	Lower Limb.
3. Short irregular **wrist-bones** (carpal bones).	3. Short irregular **ankle-bones** (tarsal bones).
4. Bones of hand—(*a*) **metacarpal bones** supporting undivided part of hand, (*b*) **finger-bones** (phalanges).	4. Bones of foot—(*a*) **metatarsal bones** supporting undivided part of foot, (*b*) **toe-bones** (phalanges).

SKULL.

General Construction.—The greater part of the skull consists of a rounded bony box, the **brain-case** or **cranium** (Gk. *craniŏn*, skull), in which the brain is lodged. Its dome-like roof, which is practically all that can be seen in a top view of the skull, is adapted to resist very considerable pressure. An egg-shell is difficult to crush for a similar reason. In a front view of a skull it is the cranium which constitutes the forehead and roofs the eye-sockets (**orbits**), while the cranium also makes up the back of the skull. A view of the base of the skull (fig. 6) shows the floor of the cranium pierced by a large roundish hole, the **foramen magnum** (L. for large hole), through which the spinal cord is continued into the brain.

The rest of the skull is known as the **facial portion**. It completes the orbits, walls the cavities of the nose, and includes the framework of the jaws and roof of the mouth.

Bones of the Cranium.—A large **frontal** (L. *frons*, *frontis*, front) bone (fig. 5) roofs the orbits and the nasal cavities in part, makes up the forehead, and constitutes the front of the cranial roof and side-walls. Just behind it come two arched **parietal** (L. *paries*, wall) bones, which complete the roof, continue the side-walls, and form part of the back of the brain-case. The transverse join behind the frontal is known as a **suture** (L. *suturus*. seam), this name being given because there are two jagged interlocking edges, looking something like an irregular row of stitches. Such an union is extremely firm, and its strength is increased by the fact that the edges are bevelled. The two parietals are connected together by a longitudinal suture of similar kind. Behind the parietals and united with them by a transverse suture is situated the large **occipital** (L. *ob*, against; *caput*, head) bone, which makes up the back of the cranium and also the hinder part of its floor (figs. 5 and 6). Below it is perforated by the foramen magnum, and on each side of this there is a smooth oval projection or **occipital condyle**

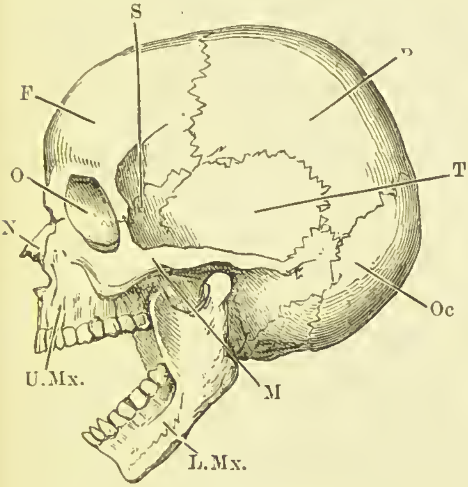

Fig. 5.—Bones of the Skull.

F, Frontal; P, parietal; Oc, occipital; T, temporal; S, sphenoid; O, orbit; U. Mx., upper maxillary; M, malar; N, nasal; L. Mx., lower maxillary.

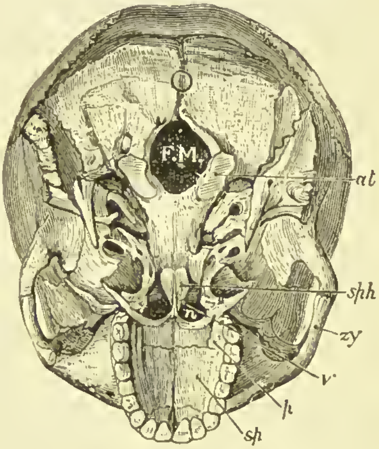

Fig. 6.—The Base of the Skull.

F. M. Foramen magnum; *at*, occipital condyle; *sph*, sphenoid; *v*, vomer; *p*, palate bone; *sp*, palatine plate of maxilla; *zy*, zygomatic arch.

(Gk. *cŏndulŏs*, knuckle-like knob), which fits into a corresponding pit on the top joint of the backbone. The side-wall of the cranium below the parietal is mainly formed by a moderately large **temporal** (L. *tempora*, temples) bone, so called because of its relation to the region above the ear known as the 'temple'. This bone is divided into three distinct regions:—(*a*) a **squamous** part above, uniting by suture with the parietal, and overlapping this bone in a scale-like way, hence its name (L. *squama*, fish-scale); (*b*) a **mastoid** part (Gk. *mastos*, breast) behind, constituting the small rounded projection which can easily be felt just behind the ear; (*c*) an exceedingly dense **petrous** (Gk. *pĕtrŏs*, stone) part below, which encloses the essential parts of the organs of hearing, and projects somewhat into the cranial cavity. A bony bar, the **zygoma** (Gk. *zugōma*, bar), projects forwards from the squamous portion, and makes up the hinder part of the **zygomatic arch** (fig. 6), which runs back from the orbit. On the under side of the zygoma, just at its root, there is a transverse hollow into which the lower jaw is jointed. Behind this **glenoid cavity** (Gk. *glēnē*, socket; *eidŏs*, resemblance) will be noticed, in the petrous portion, a rounded hole with jagged edges. This is the external opening of the ear.

The floor of the cranium, in front of the occipital, is made up by two very irregular bones, the sphenoid and ethmoid. The **sphenoid** (Gk. *sphēn*, a wedge) receives its name because it is wedged in between the other bones of the skull. It consists of an irregular central part which unites with the occipital behind, and two wing-like projections on each side, of which the smaller front one is called the 'lesser wing', and the larger back one the 'greater wing'. Besides this there is a double plate projecting downward on each side, and acting as a buttress to support the hinder part of the palate and upper jaw. The greater wings help not only to floor the cranium, but also to make up its side-walls (fig. 5, S) and to bound the orbit. The lesser wings also help to floor the cranium and roof in the back of the orbit.

The **ethmoid** bone (Gk. *ĕthmŏs*, sieve; *eidŏs*, resemblance), which will be more fully considered in connection with the sense of smell, is much smaller than the sphenoid, and consists of three parts:—(1) a horizontal **cribriform plate** (L. *cribrum*, sieve; *forma*, resemblance). perforated by numerous small holes and completing the cranial floor in front of the sphenoid; (2) a **vertical plate** of bone between the upper parts of the right and left cavities of the nose; (3) an irregular spongy **lateral mass** on each side of this, divided into scroll-like *superior* and *middle* **spongy** or **turbinated bones** (fig. 84).

Structure of the Cranial Bones.—If these bones were of uniform texture throughout a comparatively slight blow on the head would dangerously jar the brain.

As it is, however, they consist of three layers or 'tables', (*a*) an outer layer of dense bone, (*b*) a layer of spongy bone, the **diploe** (Gk. *diploē*, doubling), by which shocks are broken (cp. p. 19), and (*c*) a thin inner layer of dense bone.

Bones of the Face.—The most important of these are the two **upper maxillary** (L. *maxilla*, jaw-bone) or upper jaw-bones. They present below a crescentic margin, containing the sockets in which the upper teeth are lodged, and the greater part of the **hard palate** (fig. 6, *sp*) is formed by two shelf-like outgrowths from them, which meet one another in the middle line. The upper maxillary bones also assist in bounding the orbits and wall in the nasal cavities outside and below. The lower and outer walls and margins of each orbit are completed by a thick, strong **malar** (L. *mala*, cheek) or cheek-bone, which unites behind with the zygoma to complete the zygomatic arch. Another and very small bone, the **lachrymal** (L. *lachryma*, tear), makes up a small part of the inner wall of the orbit, just within the margin. It is grooved so as to allow of the passage of a little tube, the **lachrymal duct**, which conducts tears into the nose.

Several small bones connected with the nasal cavities have to be mentioned. Two curved **nasal** bones help to roof them in, and a vertical plate of bone, named from its shape in side view, the **vomer** (L. *vomer*, ploughshare), stretches from the under side of the sphenoid and vertical ethmoid plate to the upper side of the bony palate. The sharp end of the vomer is directed forwards, and it largely makes up the bony part of the partition between right and left nasal cavities. An elongated **inferior** (L. *inferus*, below) **spongy** bone projects into each of these cavities from its outer wall, below the lateral mass of the ethmoid. Lastly, there is an irregular **palate** bone on each side, consisting of a vertical plate, which forms part of the outer wall of the corresponding nasal cavity, and a horizontal shelf, which makes up, with its fellow, the posterior part of the bony palate (fig. 6).

The large and strong **lower maxillary** bone or **lower**

jaw consists of a horseshoe-shaped part in which the lower teeth are embedded, and of a nearly vertical **ramus** (L. for branch) at each end of this. In side view, therefore, the lower jaw is somewhat L shaped (fig. 5.) At the top of each ramus there is a smooth, elongated **condyle,** which fits into the corresponding glenoid fossa. A large **coronoid process** (L. *corona*, crown; Gk. *eidos*, resemblance) projects from the front of the ramus. In a dog or cat the lower jaw can only move up and down like a hinge, the condyle on each side being transverse and forming a hinge-joint with its glenoid cavity. But in man the condyles are placed obliquely so that the lower jaw can be moved from side to side, or forwards and backwards, as well as up and down. This enables the food to be very thoroughly chewed.

Number of Bones in the Skull.—There are 8 bones in the cranium (not including the minute ear-bones), *i.e.* 4 *unpaired*—frontal, occipital, sphenoid, ethmoid; and 2 *paired*—parietal and temporal. The bones of the face are 14 in number, *i.e.* 2 *unpaired*—vomer, inferior maxillary; and 6 *paired*—superior maxillary, malar, lachrymal, nasal, inferior spongy bone, and palate bone.

Hyoid Bone.—In connection with the skull it is convenient to deal with the bone which receives its name from its resemblance to the Greek *u* (*Gk. v*, u; *eidos*). It is situated at the root of the tongue with the legs of the *v* directed backwards and upwards, and its curved front part ('body') can be felt below the jaw just above the projection known as 'Adam's apple', which is part of the organ of voice or **larynx** (Gk. *laru(n)gx*, throat).

BACKBONE, SPINE, OR VERTEBRAL COLUMN.

General Structure.—The backbone (figs. 1 and 7) is a hollow curved rod made up of a number of bones placed one on top of the other and locked together in such a way as to combine strength with a certain amount of flexibility. Its curved shape makes it very much stronger than it would be if straight, and also converts it into a spring by which shocks are broken instead of being transmitted upwards to the brain. It should also be noticed that the backbone broadens out below, which enables it more easily to bear the weight of the body.

Vertebrae. — This name (from L. *verto*, I turn) is given to the pieces which make up the backbone because they allow of a certain amount of twisting movement, especially in the neck and loins. 33 vertebrae can be recognized in all, (*a*) 7 **cervical** (L. *cervix*, neck) or neck vertebrae; (*b*) 12 rib-bearing, **thoracic**, or chest vertebrae; (*c*) 5 **lumbar** (L. *lumbus*, loin) or loin vertebrae; (*d*) 5 **sacral** vertebrae, closely fused together into a broad bone, the **sacrum** (L. *os sacrum*, sacred bone, from supposed occult properties), and (*e*) 4 small coccygeal or tail vertebrae fused into a little curved bone, the **coccyx** (Gk. for cuckoo), so named from a fanciful resemblance to a cuckoo's beak.

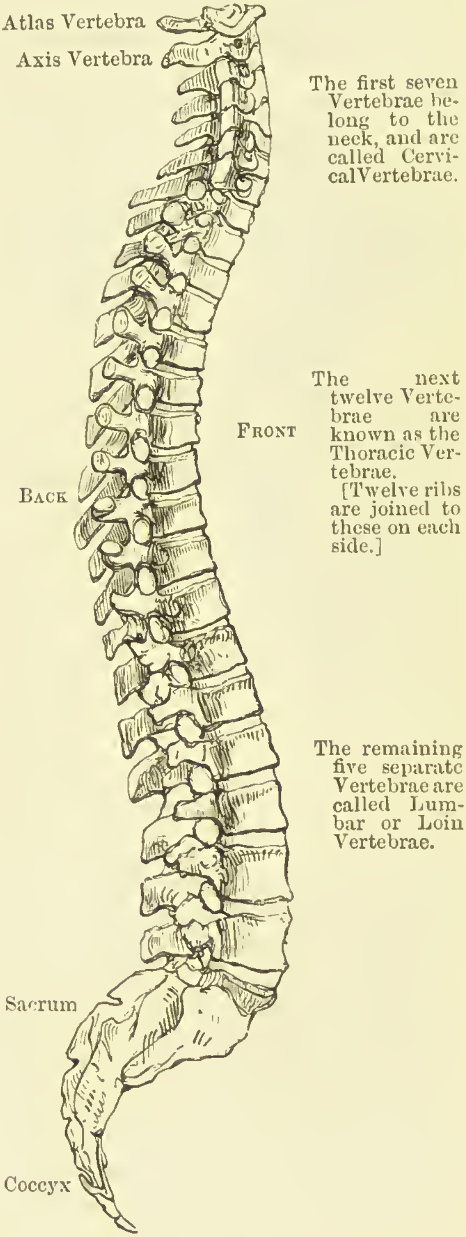
Atlas Vertebra
Axis Vertebra
The first seven Vertebrae belong to the neck, and are called Cervical Vertebrae.
The next twelve Vertebrae are known as the Thoracic Vertebrae. [Twelve ribs are joined to these on each side.]
FRONT
BACK
The remaining five separate Vertebrae are called Lumbar or Loin Vertebrae.
Sacrum
Coccyx

Fig. 7.—The Vertebral Column.

Parts of a Vertebra.—One of the thoracic may conveniently be taken as an example (fig. 8). It is a ring of bone, the cavity of which (*h*) forms part of the spinal canal. The front of the ring is very much thickened both from front to back and from top to bottom (*a*) into the **body** or **centrum** of the vertebra. The bodies of successive vertebrae are placed on top of one another like a pile of pill-boxes filled with sponge (to represent the internal spongy bone). Their surfaces are not, however, in contact but are separated by pads of cartilage, which allow of a limited amount of movement and also act like 'buffers' in preventing jolts. These pads are known, from their position, as **intervertebral discs** (L. *inter*, between).

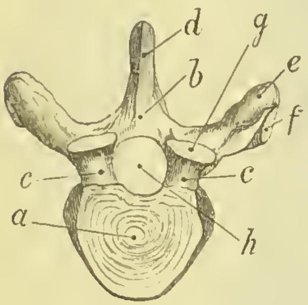

Fig. 8.—A Thoracic Vertebra.

The posterior part of the vertebral ring, the **neural arch** (fig. 8, *b c c*), bounds part of the sides and back of the spinal canal. From it a number of projections or processes arise. Some of these, the **articular processes** (*g*) lock the arch with its neighbours—others, the **transverse processes** (*e*), at the sides, and the **neural spine** (*d*) at the back, increase the surface to which muscles can be attached, and are firmly united by ligaments (cp. p. 17) Holes, the **invertebral foramina**, through which the spinal nerves run, are left between successive arches.

Differences between Vertebrae.—The description just given will apply in the main to the lumbar vertebrae and the last five of the cervical. The two first cervical vertebrae are, however, modified in such a manner as to let the head move very freely on the neck. The upper of these two vertebrae is called the **atlas** (fig. 9), a name fancifully given because it supports the rounded skull as the giant Atlas was supposed by the ancients to support the globe. The skull, in fact, is balanced on the top of the atlas with so near an approach to accuracy that very little effort is necessary to keep it held up.

The balance is not, however, *quite* accurate. There are two smooth cups which receive the occipital condyles (p. 23), and form with them a hinge-joint which allows nodding movements to be freely executed. The atlas is more like a ring than any of the other vertebrae. By means of a **transverse ligament** the cavity of the ring is divided into a large back part (spinal) and a small front part through which a bony peg passes. This peg, the **odontoid process** (Gk. *ŏdous, ŏdŏntŏs*, tooth; *eidŏs*, resemblance) projects from the body of the second or **axis** vertebra, so named because it constitutes a pivot or axis on which the skull with the atlas can turn from side to side. The peg is firmly held in place by ligaments, some of which, the '**check**' **ligaments**, run from it to the occipital bone. There are smooth surfaces upon it which play against corresponding ones on the atlas, making the movements easy. The odontoid peg is really a part of the atlas which has fused with the body of the axis. This is proved by the way it develops and by comparison with certain other animals. It is also worth noting that the atlas has scarcely any neural spine, as this would interfere with backward movements of the head, while its transverse processes are very large for the attachment of muscles which help to move the head. For the same reason as the last the spine of the axis is specially large. This is also the case with the spine of the seventh cervical vertebra, from which an elastic

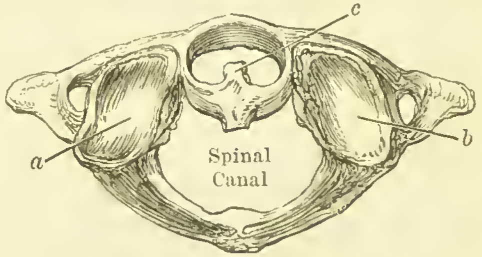

Fig. 9.—Top View of Atlas Vertebra.

a, b, The two smooth hollows on which the skull rests; *c*, the hollow or groove in which the odontoid peg of the axis fits.

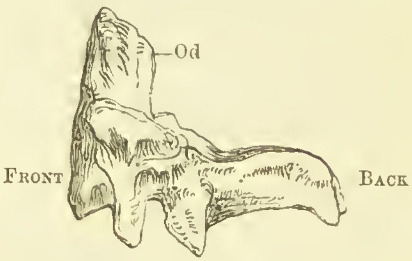

Fig. 10.—Axis Vertebra. Od, Odontoid process.

ligament (**ligamentum nuchae** = L. for neck ligament) runs to the skull and assists in keeping the head erect.

This ligament is immensely developed in such animals as the ox, where the work of keeping the head horizontal by muscular effort alone would be too exacting. It is called by butchers the "pax wax".

RIBS AND STERNUM.

Together with the thoracic vertebrae these constitute a bony cage by which the walls of the thorax are supported and protection given to the important organs contained in this region (figs. 4 and 11).

Breastbone or **Sternum** (Gk. *sternon*, breast).—This is a flat bone running down the middle of the thoracic wall (fig. 11). Its upper end (*o*) is broadened out to support the collar-bones, and a piece of cartilage (*q*) is attached to its lower end.

Ribs (fig. 11).—These are 12 pairs of long curved bones, with sharp edges above and below, and flat surfaces externally and internally. Each rib is jointed on to the backbone behind and has a **costal cartilage** (*c*) attached to it in front. The curved form of the ribs gives them great strength and elasticity, thus enabling the chest to withstand without injury very hard blows or considerable pressure. The first seven pairs of ribs (1–7) are termed 'true', because their cartilages are united directly to the sternum. These ribs increase in length from first to seventh, so as to increase the volume of the thorax. As a consequence of this the sternum, as seen in side view, is directed not only downwards but also somewhat outwards. The last five pairs of ribs, known as 'false', because their cartilages do *not* unite directly with the sternum (see fig. 11), decrease in length from above downwards. The last two pairs (*f*, *f*) are termed 'floating' ribs because their front ends are only supported by muscle. The cartilages of the first three pairs of false ribs are connected with those of the last pair of true ribs (see fig. 11).

Movements of Wall of Thorax during Breathing.—It is not enough that the walls of the thorax should be firm and strong, they must also be able to move so as to alter its volume, as otherwise the passage of air into and out of the lungs which occurs in breathing would be impossible. The ribs and sternum can be moved in such a way that the size of the chest from side to side and front to back alternately increases and diminishes. It must be remembered that, in a state of rest (fig. 11), the ribs slant downwards and forwards from back to front. They are hinged upon the backbone, which is relatively fixed. It is clear that if the ribs with the sternum are swung upwards upon these hinges the size of the chest must be *increased* from back to front. This actually occurs during **inspiration** (L. *in*, in; *spiro*, I breathe) or breathing in of air, as may be seen by watching another person's chest or placing a hand upon one's own chest. During this upward movement the chest also increases in volume from side to side, as may be realized by placing a thumb on each side of the chest and taking a deep breath, when the thumbs will be forced outwards. This results from the fact that during inspiration each rib rotates upwards on an axis corresponding to the line joining its ends.

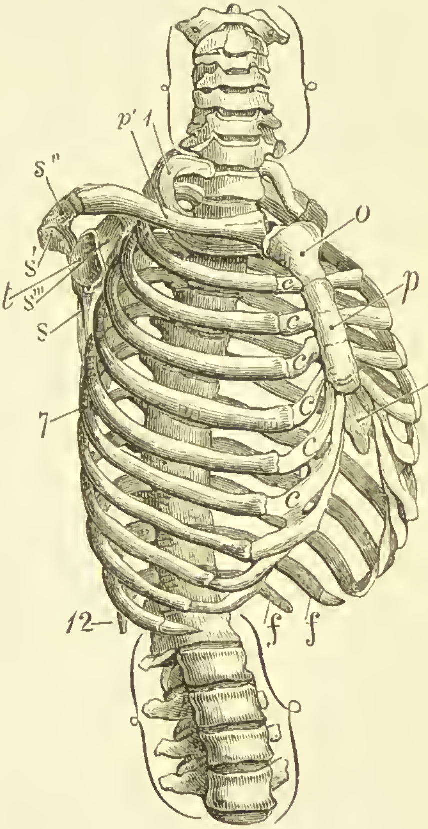

Fig. 11.—The Thorax.

The upper vertebrae enclosed in brackets are cervical, the lower lumbar. p', Clavicle; s t, scapula; s' s''', glenoid cavity; s'', acromion. Other letters explained in text.

When air is **expired** (L. *ex*, out; *spiro*, I breathe) or breathed out, movements take place which are the opposite of those just described.

Intercostal Muscles (L. *inter*, between, *costa*, rib).—The spaces between the ribs are filled up by oblique muscle fibres to which this name has been applied. There are two layers of these muscles, an outer, the **external intercostals**, in which the fibres run downwards and forwards, and an inner, the **internal intercostals**, with fibres running in the contrary direction. The two sets of fibres consequently cross one another like the two strokes of an **X**. In order to understand the action of these fibres it must be remembered that when a muscle contracts (p. 14) it becomes shorter and tends to bring together the parts to which its ends are attached. By means of a simple model devised more than a century and a half ago, and depicted in fig. 12, it may be shown that the external intercostals *raise* the ribs, and are therefore **inspiratory muscles**, while the internal inter-

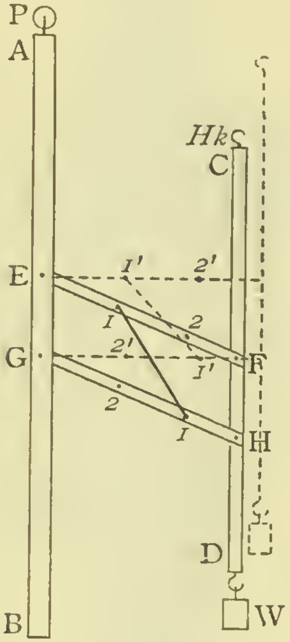

Fig. 12.—Model to illustrate Respiratory Movements of Chest, arranged to demonstrate action of External Intercostals.

A B, Relatively fixed bar representing backbone; E F, G H, laths representing ribs, and pivoted at E, F, G, H; C D, movable rod representing sternum; 1 1 is an elastic band on the stretch) representing external intercostals. The band in shortening pulls the movable rod *up* into position indicated by dots, a weight W being adjusted to prevent too great elevation. To demonstrate action of internal intercostals 1 1 is removed, the rods are placed in dotted position, and kept there by a second weight at end of a thread passing from the hook *Hk* over the pulley P. A second elastic band, shorter than the distance 2′ 2′, is then attached to pegs at the points 2′, 2′. By its shortening the movable rod is pulled *down*. Note that 1′1′ is shorter than 1 1, and 2.2 than 2′ 2′.

costals pull them down, and are therefore, probably, **expiratory muscles.** Expiration, however, is largely a matter of return to the position of rest as a result of the elasticity of the parts, aided by their weight.

SKELETON OF UPPER LIMB.

Shoulder Girdle (figs. 4, 11, 13).—This consists of **collar bone** or **clavicle**, and **shoulder blade** or **scapula**. The former, named from its resemblance to an antique key (L. *claviculus*, a small key), is an *f*-shaped bone stretching horizontally from the broad upper end of the sternum to the scapula. It supports the shoulder, and as in other cases the curved shape gives greater strength and elasticity, enabling it both to stand considerable shocks and, like a spring, to break their force. As the important blood-vessels and nerves of the arm pass under it this is a matter of great importance. The **scapula** (L. name) is a triangular bone (fig. 13) situated at the back of the thorax, with its shortest side directed upwards. Powerful muscles for moving the arm are attached to it, besides which it furnishes a shallow cup, the **glenoid cavity**, to which the bone of the upper arm is articulated. The outer end of the clavicle is connected with an arched process of the scapula known as the **acromion** (Gk. *akrŏn*, top; *ōmŏs*, shoulder) because it forms the top of the shoulder. It is the free end of a prominent ridge or 'spine' which runs across the scapula, and it protects the shoulder joint besides preventing dislocation in an upward direction.

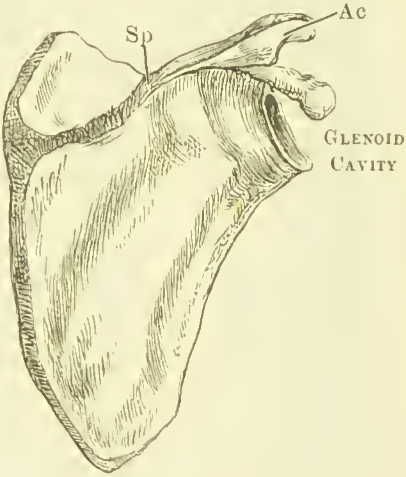

Fig. 13.—Outer Surface of the Right Scapula or Shoulder Blade.

Sp, Spine; Ac, acromion.

Free Limb (figs. 14–16).—The **humerus** (L. *humerus*, shoulder) or upper arm bone (fig. 14) consists, like all long bones, of a *shaft* and two enlarged *articular ends* which help to form joints. It is also convenient in a case like this to call the end nearer the body *proximal* (L. *proxime* next) and the other end *distal* (L. *distans*, distant). The proximal end of the humerus is mainly constituted by a large rounded surface known as the **head**, which articulates with the glenoid cavity to form a ball-and-socket joint. The head is much larger than the cavity and this enables very extensive movements to be executed, but at the same time makes the shoulder joint easy to put out. Note also that the head is set on obliquely so as to facilitate a rotatory movement inwards, which is specially useful in the case of the arm. The distal end of the humerus presents a smooth pulley-shaped surface for articulation with the radius and ulna.

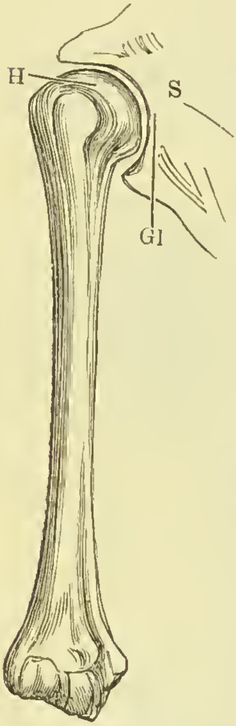

Fig. 14.—Humerus.

H, head; S, scapula; Gl, glenoid cavity.

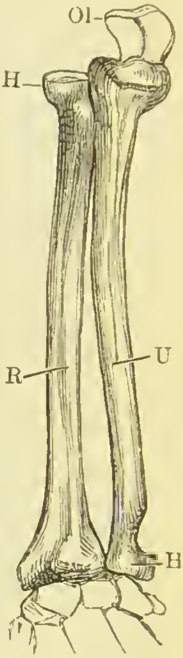

Fig. 15.—Bones of Forearm.

R, Radius, with head H; U, ulna, with head H′ and olecranon Ol.

Radius and Ulna (fig. 15).—These bones respectively support the thumb-side and little-finger-side of the forearm. The **radius** (L. for spoke of a wheel) has a small proximal end ('head') upon which is a shallow cup for articulation with part of the pulley-shaped end of the humerus. The distal end of the radius broadens out to form a support for the greater part of the hand.

The **ulna**, as its name implies (Gk. *ōlĕnē*, elbow), plays an important part in the formation of the elbow, its large proximal end articulating by means of a deep smooth cavity with the greater part of the pulley-like surface presented by the humerus. Behind this cavity the ulna is produced into a large process, the **olecranon** (Gk. *ōlĕnē*, elbow; *kranŏs*, helmet), which constitutes the sharp point of the bent elbow. It gives attachment to an important muscle by which the arm is straightened, protects the elbow-joint, and prevents the forearm from being bent back too far. The comparatively small distal end ('head') of the ulna helps to support the wrist.

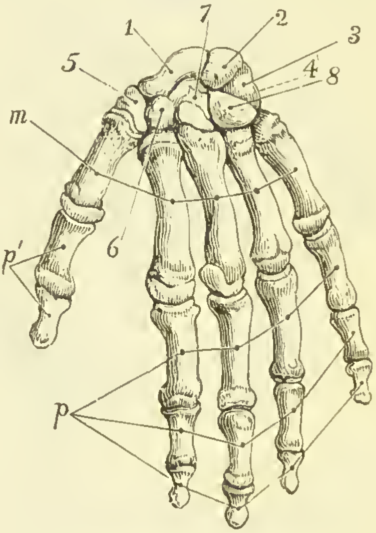

Fig. 16.—Bones of the Hand, from behind.

A dotted line leading to 4 shows the position of one carpal bone, which can be seen only from the front.

Supination and Pronation.—A very perfect hinge-joint is formed by the union of the humerus and ulna, but the head of the radius is so constructed as to allow of a certain amount of twisting movement. Keep the upper arm still and turn the palm upwards (**supine** position) as in the right arm of fig. 4. The radius and ulna are now parallel and the thumb is outside. Now turn the back of the hand upwards (**prone** position) like the left arm in fig. 4. By this movement the radius, carrying the hand with it, will have been twisted over the ulna, bringing the thumb to the inner side. During the twisting a smooth surface running round the head of the radius plays in a smooth hollow on the inner side of the ulna.

The **wrist** (fig. 16, 1–8) is supported by 8 small irregular **carpal** bones, collectively termed the **carpus** (Gk. *karpŏs*, wrist), which are articulated together so as to combine strength with great flexibility. The presence of so many bones is also of importance in preventing jarring from the shocks to which the hand is especially liable.

The 5 slender **metacarpal** bones (fig. 16, *m*) collectively called the **metacarpus** (Gk. *mĕta*, next; *karpŏs*), which support the undivided part of the hand are, like other long bones, made up of central shafts and swollen articular ends which enter into joints. The first metacarpal, which is the one supporting the thumb, articulates with a saddle-shaped surface on one of the carpal bones. This allows of very great freedom of movement, so that the thumb can be opposed to the other digits, thus enabling a number of useful movements to be executed, which would otherwise be difficult or impossible. This may be realized by attempting to pick up a pin with the *fingers* of one hand.

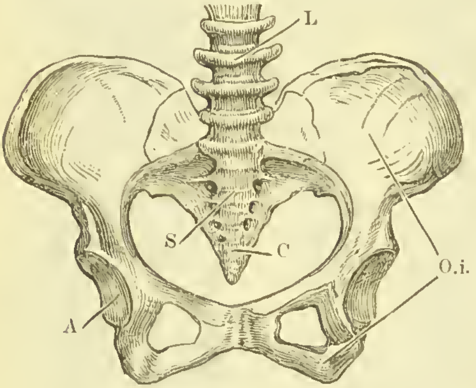

Fig. 17.—The Pelvic Bones.

L, Lumbar vertebrae; S, sacrum; C, coccyx; O. i., os innominatum; A, acetabulum.

The digits are completed by small bones, **phalanges** (fig. 16, *p*), similar to but shorter than the metacarpals. There are two phalanges for the thumb and three for each of the fingers. The end phalanges are the smallest and their free extremities are thick and rough so as to better support the tips of the digits. Owing to the inequality in length of thumb and fingers their tips can all be easily brought together in a way which is of use for innumerable purposes.

SKELETON OF LOWER LIMB.

Hip Girdle.—This is constituted on each side by a large irregular bone, the **os innominatum** (L. for unnamed bone) closely united with its fellow and with the sacrum to form an arch-like structure, the **pelvis**, so named from its resemblance to a basin (L. *pelvis*, basin). The sacrum is the keystone of this arch, which supports the weight of the trunk, and transmits it to the thigh-bones. On the outer side of each innominate bone there is a deep cavity, the **acetabulum** (L. for vinegar cup), with which the thigh-bone articulates. Important organs are contained in the cavity of the pelvis, and are thus to a large extent protected.

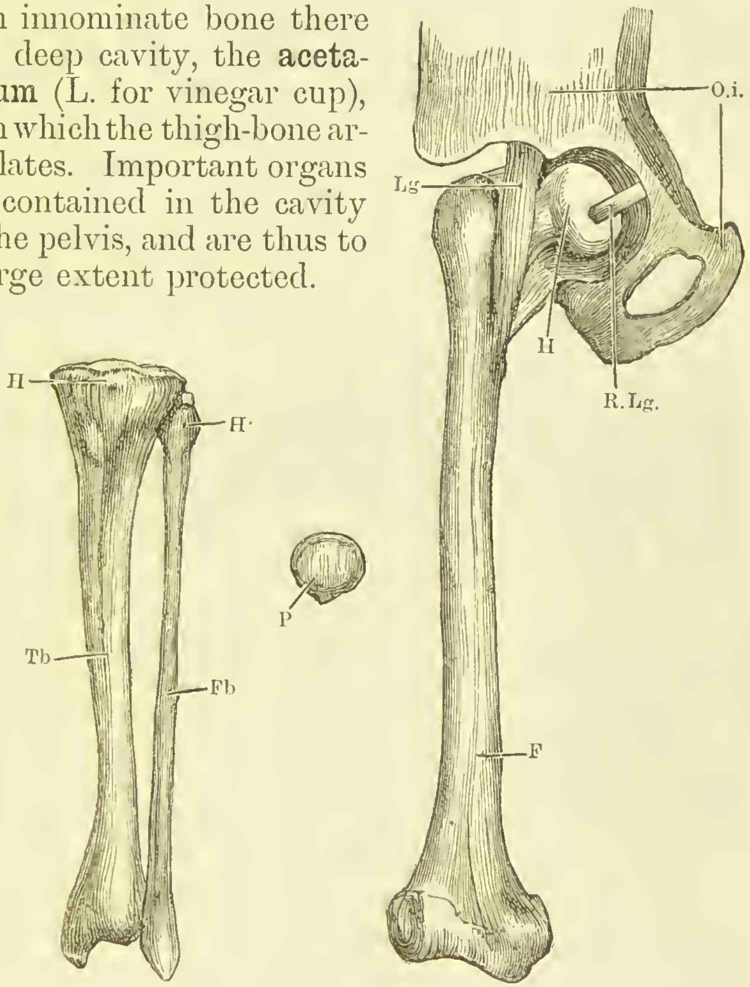

Fig. 18.—Leg Bones.

F, Femur; H, head; Lg, ligament; R. Lg., round ligament; O. i., os innominatum; P, patella; Tb, tibia; H, head; Fb, fibula; H'; head.

Free Limb (figs. 18–20).—The thigh-bone or **femur** (L. for thigh), is the longest and strongest in the body. It corresponds to the humerus, and like it consists (fig. 18) of a proximal end provided with a rounded head, a shaft, and a pulley-like distal end. The smooth globular head is not placed in a line with the shaft but on the end of an oblique ‘neck’. The result of this arrangement is to keep the legs wider apart, thus making it easier to balance the body—to form an arch by which the weight of the body is transmitted to the legs—and to afford more advantageous attachments for muscles.

Hip-joint.—In comparing this with the shoulder joint the first noteworthy point is the depth of the cup-like acetabulum, as compared with the shallow glenoid cavity. In fact the head of the femur fits so accurately into its socket that atmospheric pressure alone is sufficient to keep it in place and to support the weight of the leg. The joint is also kept firm by ligaments, one of which, the **round ligament** (ligamentum teres) runs from the head of the femur to the acetabulum (fig. 18). The result of the arrangements described is to somewhat limit the freedom of movement at the hip as compared with the shoulder, while at the same time there is greater firmness and far less likelihood of dislocation.

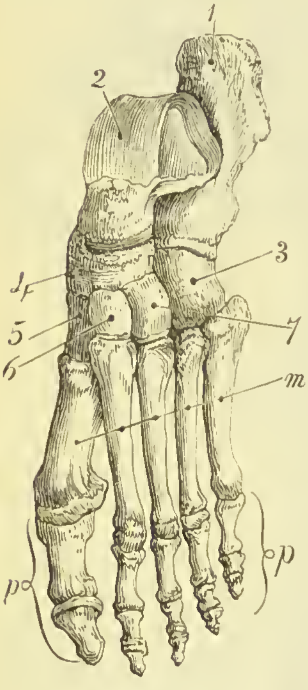

Fig. 19.—Bones of the Foot.

Tibia and Fibula (fig. 18). The **tibia** is much the larger of these two bones. Its proximal end is a broad head which articulates with the femur, while its rather narrower distal end plays an important part in the formation of the ankle-joint. The slender **fibula** presents a small head above, which does not, however, help to form the knee-joint. Its lower end is somewhat broader and enters into the ankle-joint.

Knee-joint and Patella.—The knee, like the elbow, is a hinge-joint, which, however, is here protected in front by a special bone, the knee-pan or **patella** (fig. 18), which also gives a better leverage to the muscles which straighten the leg.

The bones of the ankle or **tarsus** (Gk. *tarsŏs*, ankle) are seven in number (fig. 19, 1–7). They are much stronger and more massive than the wrist-bones, as they have to support the weight of the body, but, as in the case of the wrist, flexibility and power of breaking shocks result from the presence of a number of bones jointed together. The two largest of these bones are the huckle-bone or **astragalus** (Gk. *astragalŏs*, ankle-bone) which has a pulley-like surface above for articulation with the leg-bones (fig. 19, 2; fig. 20, B), and the heel-bone or **calcaneum** (L. *calx*, *calcis*, heel), which projects backwards to form the heel (fig. 19, 1; fig. 20, C).

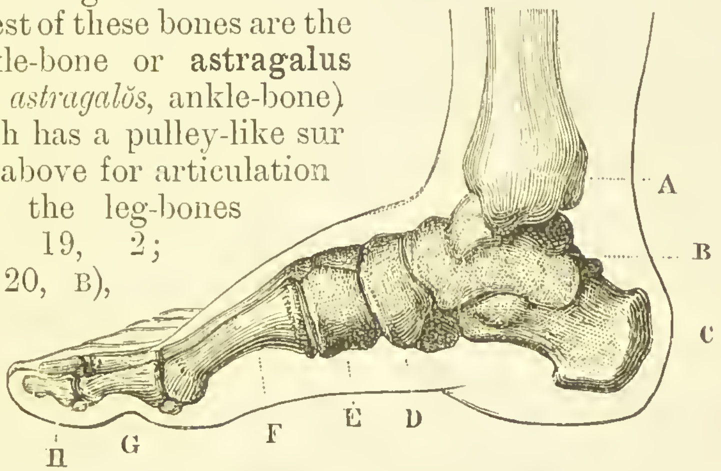

Fig. 20.—Bones of the Foot, from the side.

A, Tibia; B, astragalus; C, os calcis; D and E, other tarsal bones; F, metatarsal bone of great toe; G and H, phalanges of great toe.

The **metatarsals** (fig. 19, *m*) and **phalanges** (fig. 19, *p*), which constitute the framework of the toes, are the same in number as the corresponding bones of the fingers (p. 35), but the proportions are very different. The great toe is relatively very large (figs. 19 and 20), and cannot be opposed to the other digits, while the phalanges are comparatively short.

Arches of the Foot.—As may be seen from fig. 20 the tarsus and metatarsus together are arranged as a flexible arch from before backwards, and a similar arch from side to side is formed by the tarsal bones. This flexible double arch combines great strength with a large amount of springiness. It is worth noting that the parts of the foot which touch the ground are the heel, outer side, and toes. The great toe, in particular, has a great deal to do with supporting the weight of the body.

JOINTS.

The connections between the bones and cartilages of which the skeleton mainly consists are known as **joints** or **articulations** (L. *articulus*, joint), and they are roughly divisible into imperfect and perfect.

Imperfect Joints allow of no movement at all, as in the case of the union by suture of the skull bones—or else of limited movement, like that permitted between the vertebrae (p. 28).

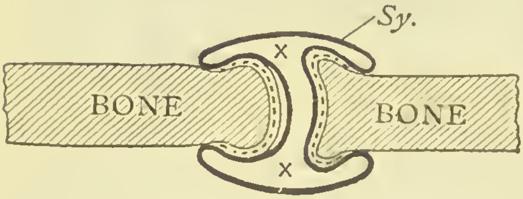

Fig. 21.—Diagrammatic Section through a Synovial Joint.

The articular ends of the bones are covered by cartilage (dotted in the fig.), and they are pulled apart so as to show the synovial membrane, which is indicated by a thick black line; x x, cavity of the synovial sac.

Perfect Joints are all distinguished by the fact that they present smooth cartilage-covered surfaces playing against one another. The passage of the smooth surfaces over one another is rendered still freer by the presence of a **synovial** (Gk. *sun*, with, *ōŏn*, egg) **membrane**, which covers them and produces a small amount of lubricating synovial fluid, popularly termed 'joint oil', though not of an oily nature. The membrane forms a sort of bag placed between the opposed surfaces (fig. 21), but under ordinary circumstances the cavity of the bag is reduced to almost nothing. As in the case of some imperfect joints the parts are connected together by strong connective tissue, bands, or ligaments of very varying shape. Perfect joints are of various kinds, according to the kind of movement allowed by the shape of the articular surfaces. The most important are the following. (1) **Hinge-joints**, such as those at the elbow, knee, and ankle, where pulley-shaped surfaces work in corresponding hollows and allow of alternate bending (flexion) and straightening (extension). Another example is the joint between the occipital bone and atlas. A variety of this kind of union is found in the *double* hinge joint, where two saddle-shaped surfaces play against one another, as is the case with the metacarpal of the thumb and its corresponding carpal bone; (2) **Ball-and-socket joints**, like those of the shoulder and hip, allow of movement in all directions, a rounded surface fitting into a cup; (3) **Pivot joints** permit of rotation, as best seen in the joint between atlas and axis, where the odontoid process of the latter constitutes the pivot. There is also a pivot joint at the elbow, between humerus and radius, in virtue of which the forearm can be brought into the position of pronation (p. 35).

BONES AS LEVERS. MUSCLES AND MUSCULAR MOVEMENTS.

A general idea of the nature of muscles has already been given (p. 14), as well as an example of their action (p. 32) in bringing about movement. A few further details may now be entered upon. The different movements of the limbs, for instance, are brought about by the action of very numerous muscles varying in size and shape, and attached to the bones. In all cases the contraction of any special muscle means that the two bones to which it is attached are brought closer together, the exact nature of the movement depending on the kind of joint between the bones. Some 240 distinct muscles exist in the human body, and of these 126 belong to the head, neck, and trunk, 112 to the limbs.

Biceps Muscle (fig. 22).—This may be taken as an example of a limb muscle. It is a spindle-shaped piece of flesh readily felt in the front of the upper arm. Its use is to flex or bend the arm by its contraction, and the shortening with corresponding thickening which takes place during this process may readily be noted in the position indicated when the forearm is bent up. The muscle is covered by a firm sheath of connective tissue, and when this is dissected away it can be divided into a number of smaller parts running longitudinally and also invested by connective tissue. Each of these parts again is a bundle or **fasciculus** (L. for small bundle) of minute cylindrical threads termed **muscle fibres**, the presence of which gives a kind of 'grain' to the flesh. Connective tissue penetrates into the muscle bundles, and in the supporting framework constituted by this tissue within and between the bundles blood-vessels and nerves branch. As will be seen from fig. 22 the central thick part (belly) of the biceps is divided into two longitudinally, each half tapering above into a strong fibrous cord of bluish-white colour, known as a **tendon** and attached to the scapula. The biceps tapers below into a third tendon which is fixed to the upper end of the radius. Tendons somewhat resemble ligaments, being, like them, made of dense fibrous connective tissue. Their use is to enable a large number of muscles to be attached to a comparatively small surface of bone, an arrangement which favours compactness and enables a muscle with a long slender tendon to act from a considerable distance. The hand, for example, would be a large and clumsy structure if all the muscles which move it were attached directly to its bones. As it is many of these are situated in the forearm and only their slender tendons are found in the hand itself, where they may readily be felt as firm cords (fig. 23).

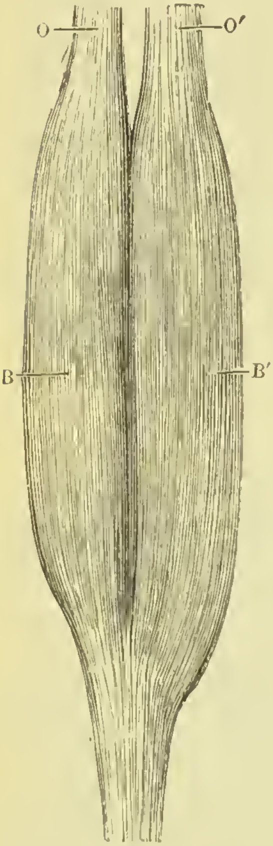

Fig. 22.—Biceps Muscle of the Arm.

B B′, Belly; o o′, origin; I, insertion.

In a muscle such as the biceps the end attached to the relatively fixed part is the **origin** (double in this case), while the other end attached to the relatively movable part is the **insertion**.

Bones as Levers.—A lever (L. *levo*, I raise) is defined in mechanics as a rigid bar (not necessarily rod-shaped) moving about a relatively fixed point. This last is termed the **fulcrum** (F), while the **power** (P), which brings about the movement is applied at another point, and the **weight** (W) or resistance to be overcome is situated at a third. Three *classes* of levers are distinguished according to the relative position of fulcrum, power, and weight. These are:—

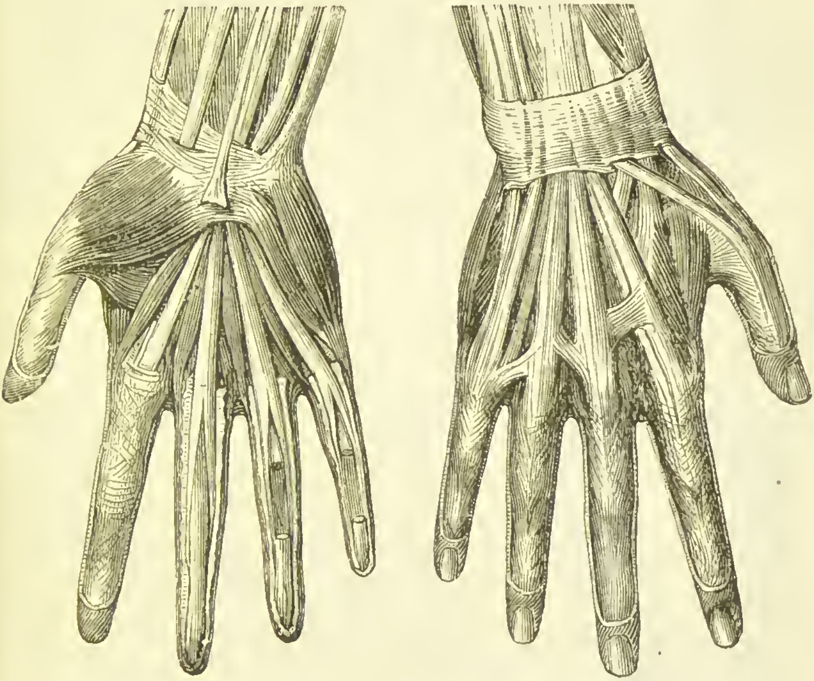

Fig. 23.—Muscles and Tendons of the Hand.

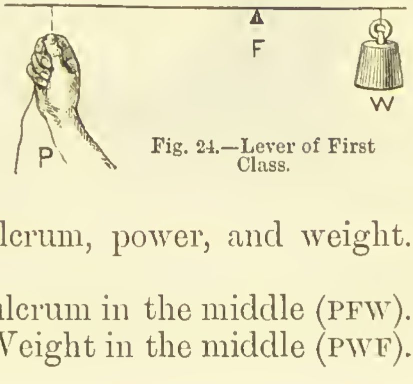

Fig. 24.—Lever of First Class.

(1) **First Class** (fig. 24). Fulcrum in the middle (PFW).
(2) **Second Class** (fig. 25). Weight in the middle (PWF).

(3) **Third Class** (fig. 26). Power in the middle (FPW). It is important to remember that a lever may be curved and of irregular shape.

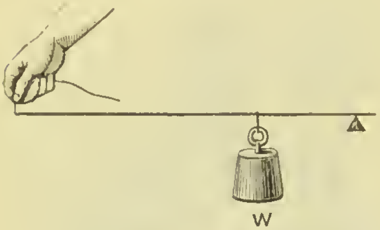

Fig. 25.—Lever of Second Class.

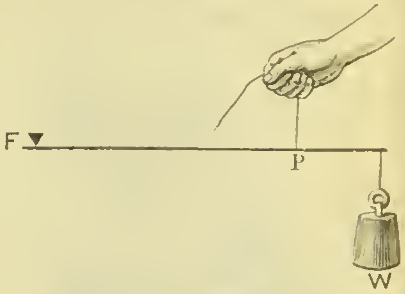

Fig. 26.—Lever of Third Class.

Examples of Levers.

(1) **First Class.** (*a*) A poker as commonly used, F being where it rests on the bar of the grate; (*b*) The skull as balanced on top of the backbone. P = muscles attached to back of head, F at occipital condyles, W = weight of head; (*c*) The pelvis as balanced on the thigh-bones and prevented from falling forwards. P = muscles attached to back part of pelvis, F at acetabula, W = weight of body; (*d*) The foot, when in sitting posture one leg is thrown over the other and toes tapped once on ground. P = calf-muscle inserted into heel-bone (figs. 27 and 28) by tendon of Achilles. F at ankle-joint. W = weight of foot.

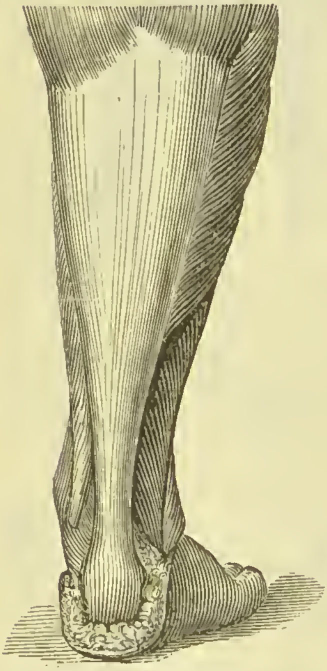

Fig. 27.—Insertion of Calf-muscle.

(2) **Second Class.** (*a*) A wheelbarrow supported by the handles. P = force applied at handles, W = weight of barrow and its contents, F at place where wheel rests on ground. (*b*) The foot as used when body is supported

on toes (fig. 28). P = calf-muscle applied to heel bone, W = weight of body, F at tips of toes.

(3) **Third Class.** (*a*) The forearm when being bent (fig. 29) at elbow joint, P = biceps muscle, W = weight of forearm and anything there may happen to be in the hand. (*b*) The foot used for pressing down the pedal of a piano, the heel resting on the ground. F at heel, P = weight of leg acting in the middle of foot and pushing it down, W = force overcome by the toes in lowering the pedal.

Levers of the first class are sometimes called **levers of stability**, because they help to keep the body and its parts in a steady position, while those of the second class are **levers of power**, because they are best adapted for doing heavy work, and those of the third class, **levers of rapidity**, because a comparatively quick movement is brought about by a small muscular contraction. It must be remembered, on the other hand, that rapidity of movement is gained by the expenditure of a relatively large amount of force.

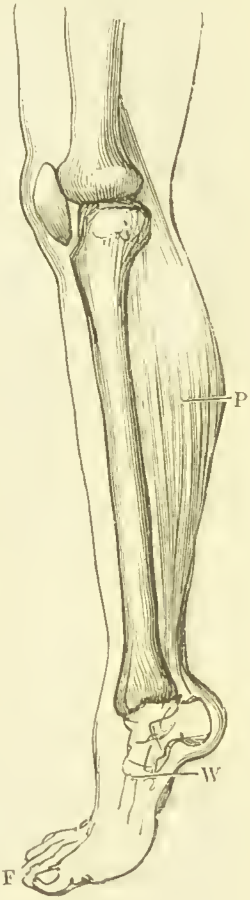

Fig. 28.

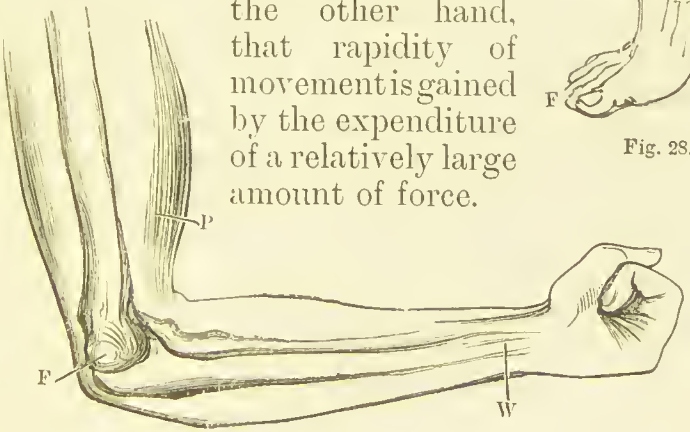

Fig. 29.

Flexor and Extensor Muscles.—Those muscles which bend or flex a limb or part of a limb are conveniently termed **flexors**, while those which straighten or extend such parts are known as **extensors**.

Upright Position of Body.—The vertical position of the body is only maintained at the expense of considerable muscular effort. Putting it broadly, there are numerous muscles situated in the front of the neck, trunk, and legs, which tend to pull the body forwards, and others placed at the back which tend to pull the body backwards. These two sets of muscles counteract one another and prevent the body from falling either forwards or backwards. In rather greater detail the facts may be stated as follows:—

(M = muscles.)

Muscles tending to pull body forwards.		**Muscles tending to pull body backwards.**
M. of front of neck....... Flat m. forming wall of abdomen...................	opposed by	M. running down back of vertebral column.
Extensor m. on front of thigh.................... ...	opposed by	Haunch m. and flexor m. on back of thigh.
Extensor m. on front of lower leg......	opposed by	Flexor m. of calf.

Voluntary and Involuntary Muscles.—All the muscles so far described, *i.e.* those which constitute the 'flesh', are called **voluntary**, because they are under the direct control of the will. They are also known as **red muscle**, from their colour, which is due to plentiful blood supply. Another kind of muscle, however, exists in the body, to which the terms **involuntary** and **white** are applied. It makes up a large part of the walls of the internal organs, is pale in colour, and not under the control of the will.

Tonic Condition of the Muscles.—Under ordinary circumstances the muscles of the body is in a half-contracted or tonic condition, as a result of nervous action. There is, therefore, a possibility of more vigorous contraction on the one hand, as when a muscle is used to bring about movement, or less vigorous contraction in the other, as when a person falls down as a result of a blow on the head.

Connective Tissue. This is a convenient place to give a few further details about this tissue which has already been frequently mentioned. A rough distinction is drawn between white and yellow connective tissue. (1) **White connective tissue** is tough and inelastic, and is seen in its purest form in tendons and most ligaments. Other examples are periosteum (p. 17), and perichondrium (p. 20), and the firm sheaths which invest muscles (p. 42). It yields gelatin on boiling or treatment with weak acid. (2) **Yellow connective tissue** is best exemplified by the ligamentum nuchae (p. 30), and differs markedly from the white in its great elasticity and the fact that it is unaffected by boiling or by the action of weak acid.

Cartilage and bone are closely allied to connective tissue, and fat may be regarded as a modified form of it.

CHAPTER III.

FOOD. DIGESTIVE ORGANS.

A preliminary notion of the subjects forming the heading of this chapter has already been given (p. 14), and further information upon them will now be given.

Composition of Food.—Food is the material from which the ever-wasting body is as constantly repaired and additions made during growth derived. In repairing a steam engine the same materials are employed as those used in its original construction, *i.e.* steel, brass, &c. The human body is, in a sense, a growing, self-repairing machine, and it is necessary to know what it is made of in order to understand the nature of the food used for repairs and growth.

Ultimate Composition of Body.—By means of dissection the body can be divided into tissues (p. 17), and a further analysis can be made by the chemist, and is made in nature during the processes of decay. But at this stage a few elementary chemical considerations become necessary.

Elements and Compounds.—Air, water, the solid framework of the globe, and the bodies of organisms, are resolvable into some seventy kinds of material which are termed **elements**, since no means are at present known of breaking them up into simpler substances. Six of these elements are of primary importance as regards the composition of the human body. They are:—**oxygen** (O), **nitrogen** (N), **hydrogen** (H), **carbon** (C), **sulphur** (S), and **phosphorus** (P), of which the first three are gases and the last three solids under ordinary conditions. The letters in parentheses are the abbreviations or 'symbols' used to express these elements.

A **compound** is a substance formed by the intimate union of two or more elements in definite proportions, and differing in properties from its components. **Water**, for instance, is composed of 8 parts of oxygen and 1 part of hydrogen, by weight, or 1 and 2 parts respectively, by volume. It differs obviously from its components, being a liquid under ordinary conditions when the temperature is between 32° F. and 212° F., while both oxygen and hydrogen are gases under the same conditions. Some of the chemical differences will appear later. Again, **carbon dioxide**, commonly called **carbonic acid gas**, and familiarly known as causing the effervescence of soda-water or ginger-beer, consists of 12 parts by weight of carbon plus 32 of oxygen. **Carbon** includes the solid substances known as diamond, charcoal, and graphite (black-lead).

Atomic Theory.—Chemical facts are most simply explained by supposing the various elements to be ultimately composed of excessively minute particles termed **atoms**, which have different weights in different elements. The atoms of the lightest known element, the gas hydrogen, are taken as the standard of comparison, and hydrogen is said to have the atomic weight 1. When, therefore, the atomic weight of oxygen is stated to be 16, it is meant that an atom of oxygen is sixteen times as heavy as a hydrogen atom, and similarly for the other elements. The above furnishes an explanation of the fact mentioned above that a compound is made up of two or more elements united in *definite* proportions.

Molecules.—The smallest amount of a compound that can exist as such is termed a molecule (L. *molecula*, a small mass). This consists of atoms of the constituent elements, and if by any means these atoms are separated from one another the molecule is said to be **decomposed.** Under ordinary circumstances an element, too, is supposed to be made of molecules, but in this case the atoms constituting the molecule are all of the same kind.

Chemical Formula.—The method of expressing a compound by an abbreviated expression, or chemical formula, will now be readily understood. Thus H_2O stands for **water**, and means that every molecule of that substance consists of two atoms of hydrogen united to one of oxygen. It is unnecessary to write the 1. It also expresses the fact that water is composed of (*a*) 2 volumes of hydrogen gas + 1 volume of oxygen gas, (*b*) 2 parts by weight of hydrogen + 16 parts by weight of oxygen. Similarly CO_2 = **carbon dioxide**, in which every molecule consists of one carbon atom + two oxygen atoms. The properties of the chief elements making up the human body may now be instructively considered.

Acids and Alkalies.[1]—The former name is given to certain hydrogen compounds which in many cases redden blue litmus paper, and which commonly have a sour taste. Alkalies, on the other hand, turn red litmus blue, and possess a soapy taste. Litmus is a vegetable colouring matter.

Oxygen.—*Atomic weight*, 16. This element, which, under ordinary circumstances, is a gas, is more abundant than any other. Mixed with other gases it makes up about one-fifth the volume of the air, and it is combined with hydrogen to form water, of which it constitutes eight-ninths by weight. About 46 per cent, by weight, of the solid part of the earth is made up of it, and something like two-thirds by weight of the human body.

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[1] These definitions are very incomplete, but may answer the present purpose. For further details chemical text-books can be consulted.

Preparation.—Certain compounds of which oxygen is a constituent can be decomposed by heat, the oxygen being driven off. One of these compounds is the red oxide of mercury, HgO, Hg being the symbol for mercury or quicksilver abbreviated from its Latin name *hydrargyrum.* From this oxide oxygen was first prepared, but the compound commonly used in the laboratory is *chlorate of potash,* which gives off the gas in abundance when heated. The addition of a small quantity of *black oxide of manganese* enables the action to take place at a lower temperature. The apparatus employed is represented in fig. 30. The chlorate of potash is placed in a glass flask, the mouth of which is closed by a perforated cork. One end of a suitably curved glass tube is fixed into the hole in the cork, while the other end dips into a vessel of water, in which a glass jar, previously filled with water, has been inverted. The flask is now heated by means of a Bunsen gas burner or spirit lamp, and oxygen soon begins to come off in a rapid stream of bubbles from the submerged end of the tube. After allowing a short time to elapse, so that the air in the flask and tube may have time to escape, the bubbles may be allowed to ascend into the jar.

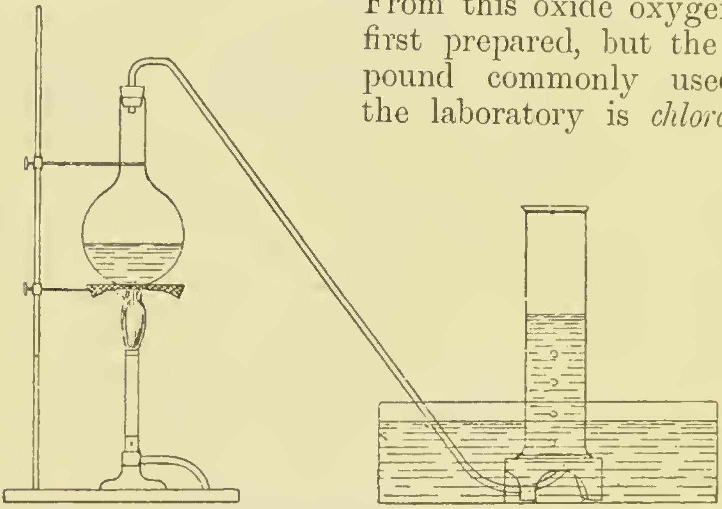

Fig. 30.—Apparatus for Preparing and Collecting Oxygen from Chlorate of Potash. as it is generally done in the Laboratory.

When this is full its mouth is closed by a greased glass plate, after which it is removed and placed right way up on the table. Several jars so collected will serve for studying the properties of oxygen. That it is **colourless** and **odourless** can easily be observed, while a glowing splinter of wood or dip candle with a glowing wick is rekindled if introduced into the jar, and goes on burning with greatly increased brightness. Oxygen is therefore a vigorous **supporter of combustion**, which fact may further be demonstrated by burning in it (*a*) fragment of *charcoal*, (*b*) a small quantity of *flowers of sulphur* placed in a small iron spoon. In the last two experiments the oxygen unites with the carbon to form *carbon dioxide*, and with the sulphur to form *sulphur dioxide*, a gas possessing a peculiarly piercing smell. The oxygen is said to **oxidize**[1] the carbon and sulphur, the process being one of **oxidation**,[1] or union of oxygen with some other substance.

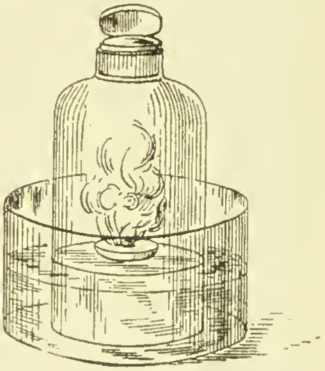

Fig. 31.—Preparation of Nitrogen.

One of the main objects of breathing is to take oxygen from the air into the body (p. 16).

Nitrogen.—*Atomic weight*, 14. This element, like oxygen, is a gas under ordinary circumstances. It constitutes about four-fifths by volume of the air, and is a very important component of the human body. *Preparation.*—The simplest method is to get rid of the oxygen in a small quantity of air by burning phosphorus in it. A small fragment of this substance is placed on a small tin saucer floating in a vessel of water (fig. 31), covered by a stoppered bell jar, and ignited with a red hot wire pushed in at the top of the jar, from which the stopper is momentarily removed. The burning phosphorus gives off dense white fumes of a compound (phosphorus pentoxide) formed by union of the oxygen with it. These dissolve in the water, and the nitrogen of the air is left behind in the jar. At the end of the experiment the water will have risen so as to fill about one-fifth of the jar, thus proving that the removed oxygen made up that proportion of the air. Nitrogen thus obtained is easily observed to be a **colourless, odourless gas**, which does *not* support combustion, and does not itself burn.

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[1] The meaning of these terms has been somewhat extended by chemists, but this does not concern the student of elementary physiology.

Hydrogen.—*Atomic weight*, 1. Like the preceding elements this, too, is a gas under ordinary conditions. It makes up one-eighth by weight of water, or two-thirds by volume. *Preparation.*—Water can be decomposed into its constituent elements, oxygen and hydrogen, by means of an electric current, but the most convenient method of preparing hydrogen is by allowing zinc to act upon dilute sulphuric acid (oil of vitriol). The apparatus employed is shown in fig. 32. On the left is a bottle in which some fragments of zinc are placed and which is closed by a doubly-perforated tightly-fitting cork. One hole of this is provided with a long tube, ending above in a small funnel, through which dilute sulphuric acid is poured, while from the other hole a curved delivery tube runs to the gas-col-

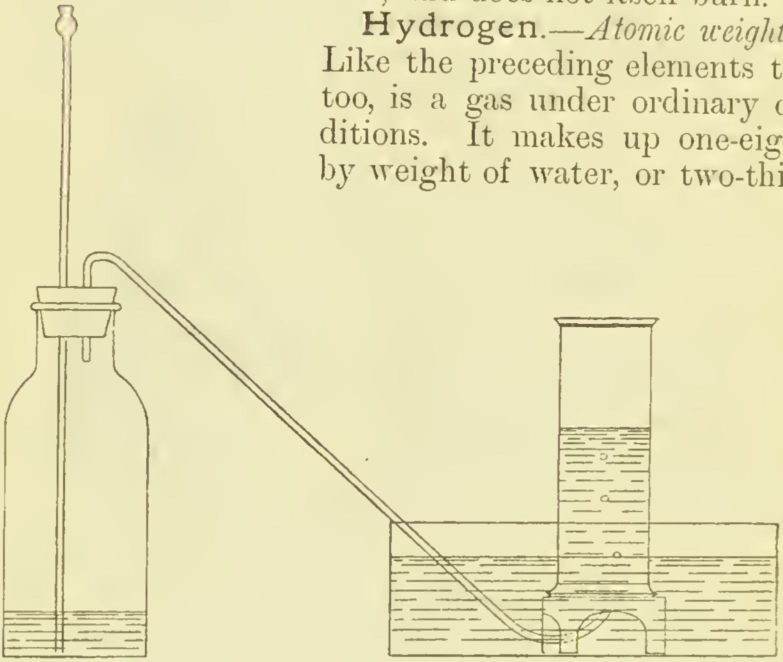


Fig. 32.—Apparatus for Preparing and Collecting Hydrogen.

lecting arrangement shown on the right. When sulphuric acid is poured into the zinc a brisk effervescence ensues, due to decomposition of the acid with escape of its hydrogen. Care must be taken to let all the air escape before the gas is collected, as a mixture of hydrogen and air is highly explosive. The collected gas is quickly proved to be **colourless** and **odourless**, and its properties must next be tested as regards combustion. A lighted candle-end supported on a bent wire and raised into a jar of hydrogen held upside down at once goes out, but the hydrogen itself takes fire and burns with a pale bluish flame at the mouth of the jar. If a tube drawn out into a fine point is substituted for the delivery tube a burning jet of hydrogen will be obtained on applying a match. The inside of a small beaker held over the jet will quickly be dimmed with moisture, the hydrogen having been oxidized into water by the oxygen of the air. Great care must be taken to let all the air escape before performing this experiment. This will not have taken place till the gas collected in a small test-tube inverted over the unlit jet burns quietly. Hydrogen, therefore, like nitrogen, does *not* support the combustion of a candle, but, unlike nitrogen, can be set on fire. The film of moisture seen on the *inner* side of the glass of a just lit lamp results from union of the hydrogen of the oil with the oxygen of the air to form water.

Carbon.—*Atomic weight*, 12. This is a solid element existing in the three forms of **charcoal**, **graphite** (black-lead), and **diamond**. It is a very characteristic component of plants and animals, and is known in such an immense number of compounds that the study of these constitutes a distinct branch, organic chemistry, so named because these compounds were first known as resulting from the life of organisms.

Sulphur (Brimstone).—*Atomic weight*, 32. This element is familiarly known as a yellow solid, which burns with a pale blue flame, being oxidized into sulphur dioxide during the process (p. 51).

Phosphorus.—*Atomic weight*, 31. The commonest form of this element is a pale wax-like solid, exceedingly inflammable, for which reason it is usually kept under water and must not be handled with the fingers.

Certain other elements of importance in the human body will be mentioned later on.

Chemical Classification of Food-stuffs.—It is a matter of common knowledge that the food does not consist of elements. The necessary carbon, for example, could not be obtained from a meal of charcoal. In fact the food is made up for the most part of very complex organic compounds, obtained by herbivorous animals from plants, by carnivorous forms from animals, and by omnivorous forms, like ourselves, from both sources. The animal kingdom is ultimately dependent upon green plants, which are able to build up their complex bodies out of simple inorganic compounds.

It is convenient to divide foods into

FOODS.

I. NITROGENOUS.
Proteids or **Albuminoids,**
consisting of the elements
N, C, H, O, S, and sometimes P.

II. NON-NITROGENOUS.

(1) **Carbohydrates.** (2) **Fats.** (3) **Mineral Salts.** (4) **Water,** H_2O.

(1) and (2) consisting of the elements
C, O, H.

Nitrogenous Foods.—These embrace a large number of exceedingly complex substances known as proteids (Gk. *prōtŏs*, first; *eidŏs*, shape), or albuminoids, using the terms in their broadest sense. They make up the greater part of lean meat, eggs, and cheese. A proteid compound is called *complex* because each molecule contains a very large number of atoms, and so little is known about these bodies that their chemical formulæ are matters of speculation, and hence their properties cannot be predicted by the chemist. The percentage composition is fairly well known, and has been calculated at

C.	H.	N.	O.	S.
51·5	6·9	15·2	20·9	0·3
to 54·5	7·3	17·0	23·5	2·0

and some of them contain a small quantity of phosphorus as an essential constituent.

The following are examples of proteids, the substances containing them being named:—*myosin* and *syntonin*, lean meat; *albumin*, white of egg; *casein*, cheese; *fibrin*, in clotted blood; *gelatin*, obtained by boiling connective tissue and bones; *gluten*, the sticky substance left behind when flour is kneaded in a fine muslin bag under a tap; *legumin*, in peas, beans, and lentils.

Carbohydrates.—These are composed of carbon, hydrogen, and oxygen, the last two being in the same proportion as in water (H_2O). Starch, sugar, and gum are examples.

Fats.—These also consist of carbon, hydrogen, and oxygen, but they contain a larger proportion of hydrogen than the last kind of food. All fatty and oily substances are included here.

Mineral Salts.—The bones and teeth owe their hardness to mineral matter, chiefly consisting of 'bone earth' or **phosphate of lime**, and partly of **carbonate of lime.** The former is a compound made up of phosphorus, oxygen, and a metallic element, **calcium** (Ca), while the latter, of which chalk is a form, contains calcium, carbon, and oxygen. These compounds of lime are necessary food constituents.

Another indispensable compound is common salt, **sodium chloride** (NaCl), each molecule of which contains one atom of a metallic element, **sodium** (Na from L. *natrium*), and one of a gaseous element, **chlorine** (Cl).

Compounds of **iron** are also necessary.

When a body is cremated the 'ash' left behind consists of the mineral salts.

Water (H_2O).—This makes up the greater part of the body, and is consequently a necessary food compound.

Percentage Composition of the Body.—The six classes of compounds just described enter into the composition of the body in the following proportions:—

	Proteids	Carbohydrates	Fats	Mineral Salts	Water
Per cent,	18·0	0·1	15·4	5·5	61·0

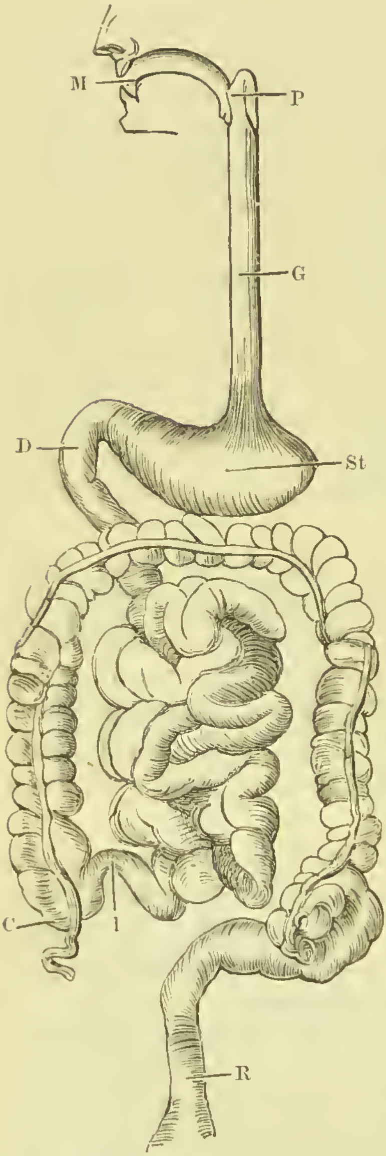


Fig. 33.—Alimentary Canal, including mouth (M), pharynx (P), gullet (G), stomach (St), small (D to I) and large (C to R) intestines.

Parts of Digestive Organs and their Arrangement.—Reference should be made to what has been said on page 15. The **alimentary canal** or **food-tube** is represented diagrammatically in fig. 33, from which it will be seen that it is by no means of uniform calibre, and to this may be added that its walls are not of uniform thickness. The stomach and intestines do not lie loose in the abdominal cavity, but are fixed to its posterior wall by folds, known as the **mesentery** (Gk. *mĕsŏs*, middle: *ĕntĕron*, bowel), of a moist, shining membrane. The cavity is lined by a similar membrane, the **peritoneum** (Gk. *pĕri*, around: *teinō*, I stretch) with which the mesentery is continuous, and of which it may be regarded as a part. The whole of the alimentary canal is lined by a sort of soft skin, the **mucous membrane**, which is of a reddish colour, richly provided with blood-vessels, and, except that belonging to the mouth, not very sensitive.

The junction between skin and mucous membrane is seen at the lips.

Nature of Digestion.—The food is broken down mechanically in the alimentary canal and also subjected there to the chemical action of several digestive juices. As a result of this the nutritious part of the food is 'digested', *i.e.* either dissolved or brought into a finely divided condition. The innutritious and undigested remains of the food pass out of the body as the **fæces**, which for the most part do not result from the waste of the body itself.

Mouth (fig. 34).—The fleshy **lips** which bound the mouth opening constitute the front wall of the mouth. The roof of the mouth is known as the **palate**, and its front part (*a*), supported by the maxillary and palatine bones, is the **hard palate**, behind which is the fleshy **soft palate** (*b*). This is continued backwards and downwards as the posterior boundary of the mouth, and it ends below in a small rounded projection, the **uvula** (*u*), easily seen on looking into the widely-opened mouth. The limits of the hard palate are marked out by a projecting ridge, the **upper gum**, in which the **upper teeth** are imbedded. The roof of the mouth is at the same time the floor of the nasal cavities (*n*). The side walls of the mouth are the muscular **cheeks**, while the **tongue** (*t*) rises up from its floor, the outer margin of which is

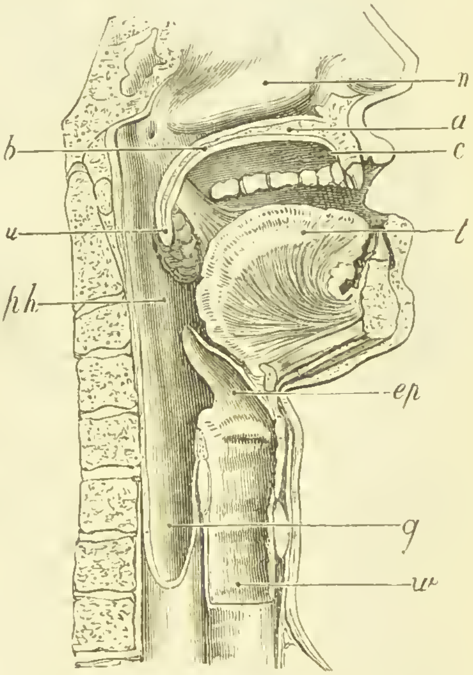


Fig. 34.—Section showing Mouth and Nasal Cavities, Gullet, Windpipe, &c.

t, Tongue; *ph*, pharynx; *ep*, epiglottis; *g*, gullet; *w*, windpipe. For other references see text.

marked by the **lower gum**, in which the **lower teeth** are imbedded. The tongue is almost entirely composed of voluntary muscle.

Teeth.—These are the hardest structures in the body, and consist chiefly of phosphate of lime. The first teeth, present in the child, are 20 in number and make up the **milk dentition.** The second or **permanent dentition** (fig. 35) consists of 32 teeth. There are three sorts of milk teeth: (*a*) **incisors** or cutting teeth, placed in front, (*b*) **canines**, and (*c*) grinding teeth, milk **molars.** The relative number may conveniently be expressed by a **dental formula** as follows:—

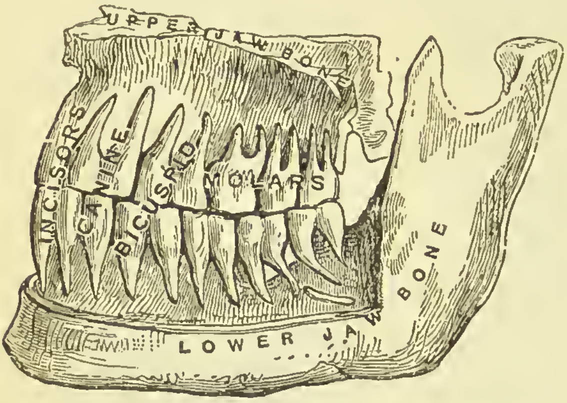


Fig. 35.—Side View of Jaw with Permanent Teeth. Bone cut away to show their roots.

$$i=\frac{2-2}{2-2},\ c=\frac{1-1}{1-1},\ m.m.=\frac{2-2}{2-2}=20$$

where i = incisor, c = canine, and $m.m.$ = milk molar. In each fraction the numerator gives the upper and the denominator the lower teeth, while the dashes stand between the teeth of opposite sides.

Permanent Teeth (figs. 35 and 36).—The milk incisors and canines are succeeded by the same number of *permanent* incisors and canines, the milk molars by the same number of permanent teeth termed in this case **bicuspids** or **premolars.** Behind these last come three **permanent molars** on each side above and below. These have no predecessors in the milk dentition. The dental formula is

$$i.=\frac{2-2}{2-2},\ c.=\frac{1-1}{1-1},\ p.m.=\frac{2-2}{2-2},\ m.=\frac{3-3}{3-3}$$

where *p.m.* = premolar and *m.* = molar. The four hindermost molars are the 'wisdom' teeth, and it is only in some cases that they are all cut.

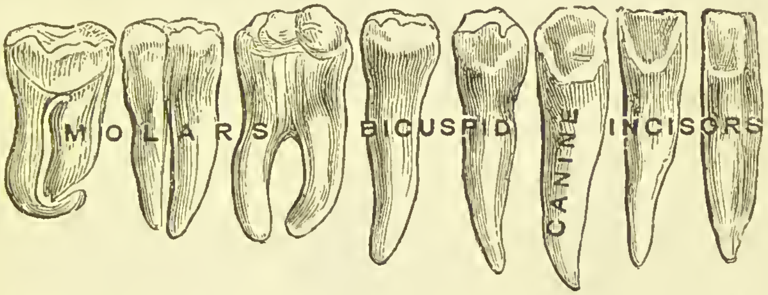


Fig. 36.—Kinds of Teeth. This figure shows the eight teeth in one half of a jaw.

Structure of Teeth (fig. 37).—The projecting part of a tooth is the **crown** (chisel-edged in incisors, pointed in canines, and with a grinding surface in the other kinds), while the rest of it is made up of one or more tapering **fangs** imbedded in the jaw. Incisors, canines, and premolars possess a single fang, molars, two or three. The slightly-narrowed junction between crown and fang is called the **neck**.

A magnified section through a molar tooth is represented in fig. 37, which shows the central **pulp cavity** present within the crown and continued into the fangs. The 'pulp', which occupies the cavity, consists of a framework of connective tissue traversed by blood-vessels and nerves, which enter it by means of a small hole situated at the tip of each fang (not seen in figure).

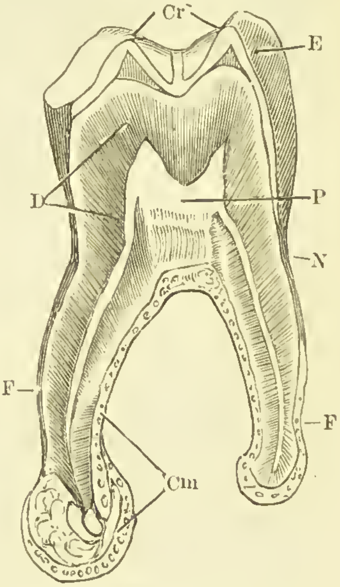


Fig. 37.—Section of a Tooth.

Cr., Crown; N, neck; F F, fangs; P, pulp cavity; E, enamel; D, dentine; Cm., cement.

The greater part of the tooth is made up of **dentine**

(L. *dens*, tooth) or **ivory**, covered by an extremely hard substance—**enamel**—in the crown, and by a layer of bone in the fangs. This last is termed **cement.** Enamel contains 96½ per cent, and dentine 72 per cent of mineral salts, the rest consisting of animal matter.

Pharynx (fig. 34, *ph*).—This name (Gk. for throat) is given to the second section of the alimentary canal, into which the mouth opens behind. It is a tube of about 4½ inches long, which lies immediately in front of the upper cervical vertebrae, and may be considered as the dilated upper end of the gullet. There are seven openings communicating with the cavity of the pharynx: (1) the opening from the mouth, on each side of which is a small oval swelling, the **tonsil**; (2 and 3) two small apertures, the **posterior nares** (L. *nares*, nostrils); one at the back of each nasal cavity; (4 and 5) on each side, close to the preceding, the small opening of one of the **Eustachian tubes**, which communicate with the drums of the ears; (6) the **glottis**, (Gk. name for it) or aperture of the larynx below; and (7) the opening at the lower end of the pharynx, where it becomes continuous with the gullet. A flexible flap, the **epiglottis** (Gk. *ĕpi*, upon; *glōttis*) projects upwards in front of the glottis at the root of the tongue (fig. 34, *ep*). Air breathed in through the nose passes back in the nasal cavities, through the posterior nares into the pharynx and thence through the glottis. Air breathed out through the nose, takes the same course in reverse order.

Gullet or **Œsophagus.**—This is a thick-walled tube, some 9 or 10 inches long, which runs just in front of the backbone through the neck and upper part of the thorax, comes a little forwards in the lower part of the thorax, pierces the diaphragm, and becomes continuous with the stomach.

The **stomach** (fig. 38) is a muscular, somewhat pear-shaped sac lying across the upper part of the abdominal cavity, with its long axis sloping downwards from left to right, and its broad end to the left. This broad part of the stomach is termed the **cardiac** (Gk. *cardia*, heart)

end, while the other extremity, which is thicker walled, and passes into the intestine, is known as the **pyloric** (Gk. *pylōros*, gate-keeper) **end.** The gullet opens into the upper side of the stomach at the junction of the cardiac and pyloric portions. When fully distended the adult stomach is capable of holding about two quarts.

The **small intestine** (fig. 39, *d e f*) is a greatly convoluted and rather thin-walled tube, situated in the middle and lower part of the abdomen. It is about 20 feet long and rather broader (nearly 2 inches) at its beginning than at its end (about 1¼ inch). The first part of the small intestine, that succeeding the stomach, is known as the **duodenum** (L. *duodeni*, twelve, *i.e.* 12 finger-breadths long), and forms an **U**-shaped loop about 10 inches long. It is followed by the **jejunum** (L. *jejunus*, empty; because commonly found so) which constitutes about two-fifths of the rest of the small intestine, and this by the **ileum** (Gk. *eileō*, I coil) which is the last part of it. These three regions are not sharply marked off from one another as the gullet is from the stomach or the stomach from the duodenum.

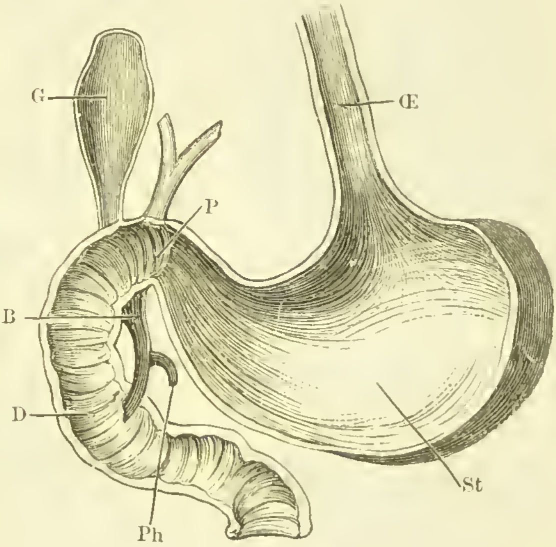
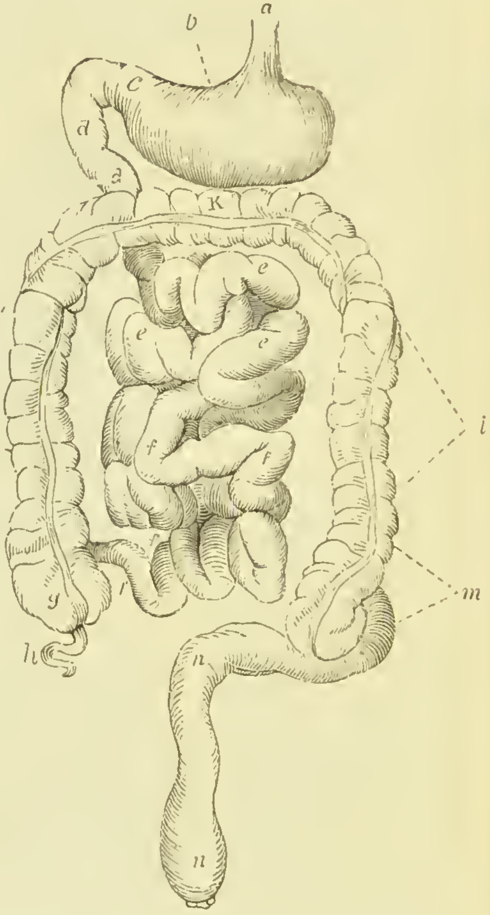


Fig. 38.—Stomach, &c.

Œ, Gullet; St., stomach; P, pyloric opening; D, duodenum; G, gall-bladder; B, bile-duct; Pn., pancreatic duct.

Large Intestine (fig. 39).—The ileum ends in the lower part of the abdomen, on the right hand side, and there opens obliquely into the large intestine, which is from 5 to 6 feet long and of greater diameter than the small intestine, as its name indicates. The large intestine begins in a rounded pouch, the **cæcum** (L. for blind) situated below the opening of the ileum and continued into a narrow process, the **vermiform appendix** (L. for worm-shaped appendage). The cæcum passes above into the **colon** (Gk. *cōlŏn,* division), which is distinguished by its puckered walls, and runs up the right side of the abdomen, across at a lower level than the stomach, and then down the right side, ending in an **S**-shaped twist, the **sigmoid flexure** (Gk. Σ, capital S; *eidŏs,* resemblance). The last eight inches or so of the large intestine occupy



a, The gullet, or œsophagus, which is continued from the back part of the mouth to
b, The stomach.
c, The pylorus, the small end of the stomach where it opens into the first part of the small intestine. At the pylorus is a thickened portion of the stomach wall, which acts as a valve to prevent the food leaving the stomach till the proper time.
d d, The duodenum or commencement of the small intestine.
e e e, The second part of the small intestine, called the jejunum.
f f f f, The third and terminal portion of the small intestine, termed the ileum.
g, The cæcum. This is the commencement of the large intestine, and between it and the ileum there exists a valve which prevents the return of any of the contents of the large intestines back into the small. This is called the ileo-cæcal valve.
h, A round worm-like process of the cæcum, which is termed the vermiform process.
i, The first portion of the large intestine, called the ascending colon.
K, The transverse colon.
l, The descending colon.
m, A part of the large intestine which is curved on itself, somewhat in the form of the letter S, and termed the sigmoid flexure of the colon.
n, The termination of the large intestine and alimentary canal, named the rectum.

Fig. 39.—The Alimentary Canal.

the back part of the pelvic cavity, and constitute the **rectum** (L. for straight), which has thicker walls than the colon, and is not puckered.

Structure of Alimentary Canal.—A common plan of structure is exhibited by gullet, stomach, and intestine, to explain which it will be found convenient to begin with the small intestine (fig. 40). This is made up of four **coats** or **layers**, which are, from without inwards, (1) a thin *serous coat* consisting of peritoneum (p. 56), (2) a coat of involuntary or pale *muscle* (p. 46) made up of an external layer of fibres running longitudinally (*e*), and an internal 'circular' layer in which the fibres run transversely (*d*), (3) a thin *submucous coat* (*c*) of coarse connective tissue traversed by good-sized blood-vessels, (4) the *mucous membrane* (*a b*). The last coat is easily peeled off owing to the ready tearing of the submucous tissue. When a piece of small intestine is cut open and examined under water the mucous membrane will be seen to form transverse folds, and to have a velvety look. Examination with a simple lens will demonstrate innumerable minute finger-like projections, the **villi** (L. *villus*, shaggy hair), shown in figs. 40 *a*, 41, 42, and 51. Between these villi an immense number of deep tubular pits can be made out in a thin slice or section by aid of the microscope. These are called the **glands of Lieberkühn** (after an anatomist of that name). The mucous membrane consists of an exceedingly thin layer of muscle externally, then of fine connective tissue traversed by blood-vessels, nerves, and other structures, and, lastly, of epithelium, which lines the cavity of the intestine. The

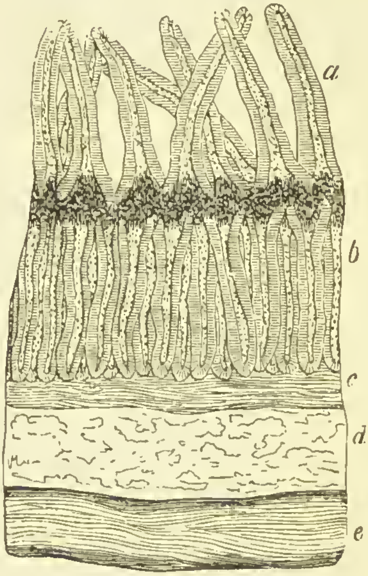


Fig. 40.—Microscopical Structure of the Small Intestine, as seen in cross section.

term **epithelium** (Gk. *ĕpi*, upon; *thallō*, I grow) is applied to a kind of tissue which forms layers covering surfaces and lining cavities. The epidermis or outer part of the skin is of this nature, and so is the innermost layer of all parts of the mucous membrane. Examination of epithelium by means of the microscope shows that it consists of minute elements known as **cells**, the nature of which varies in different cases. Cells are the units of structure, and not only epithelium but all the other tissues consist of them, and of other parts produced by them or from them. A cell essentially consists of a minute portion of the living substance, **protoplasm** (Gk. *prōtŏs*, first; *plasma*, anything formed), on which all the functions of the body depend. A small particle of the protoplasm is of special nature, and constitutes what is known as the **nucleus** (L. for kernel). Fig. 42 represents part of a longitudinal section through a villus as seen under the microscope. It is covered by **simple columnar epithelium**—simple, because consisting of a single layer of cells; columnar, because these cells are shaped like little columns or prisms set at right angles to the surface. The epithelium lining the stomach, small intestine, and large intestine is, in the main, of this kind.

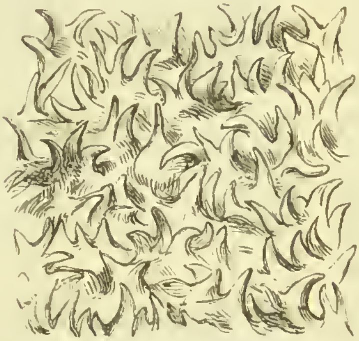


Fig. 41.—Piece of Inner Surface of Intestine, showing the Villi magnified.

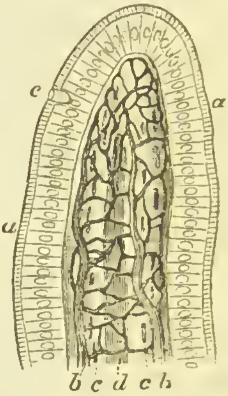


Fig. 42.—A Villus of the Small Intestine, largely magnified. *a*, Columnar cells; *e*, goblet cell, modified columnar.

A **gland** is to be defined as a more or less complicated pocket or pouch of mucous membrane, the epithelium of which is able to form or secrete some special substance or substances from the blood with which the organ is supplied. Single cells may also constitute glands, as is the case with *goblet cells* (fig. 42, *e*), which secrete mucus and are abundantly present in the epithelium of mucous membrane.

The **glands of Lieberkühn** are among the simplest, and their secretion is known as **intestinal juice**.

The **large intestine** chiefly differs from the small intestine in the absence of villi, but glands of Lieberkühn are present as before, and their minute openings can be seen with a lens. The puckered appearance of the colon is due to the layer of longitudinal muscle being thickened into three flat bands which are shorter than the part of the wall between them, and cause it to be thrown into pouches. A similar appearance can be produced in, say, the sleeve of a dress, by taking three broad pieces of elastic rather shorter than it, and, while keeping them stretched to the same length, sewing them to it. If the pieces of elastic are now allowed to shorten the sleeve will be thrown into pouch-like folds.

Where the ileum opens into the cæcum there is an **ileo-cæcal valve**, consisting of two folds of mucous membrane, which project into the cavity of the caecum and prevent the contents of the large intestine from passing back into the ileum. At the end of the rectum its layer of circular muscle is thickened into a **ring-muscle** or **sphincter** (Gk. *sphi*(*n*)*gō*, I choke), which, together with a similar ring of voluntary muscle placed below it, serves to keep the external opening closed.

The relatively very thick wall of the **stomach** possesses a well-developed muscular coat, which, in the upper part of the organ, includes a layer of *oblique* fibres within the circular ones.

The mucous membrane is thick, smooth, and, except when the stomach is full, thrown into a number of longitudinal folds, or **rugæ** (L. *ruga*, wrinkle). On examination with a lens innumerable minute pits can be seen, which mark the openings of the **gastric** or **peptic glands.** These, like the glands of Lieberkühn, are tubular depressions, and in a section (fig. 43) are seen to be packed very closely together. Their ends are branched, and lined (fig. 43, A) with **glandular epithelium,** by which the **gastric juice** is secreted.

The glandular cells are of two kinds, (1) **central** or **chief cells,** somewhat cubical in shape, (2) ovoid **parietal cells** (black in the figure). The latter are absent in the glands of the pyloric part of the stomach. That part of each gland which opens on the surface of the mucous membrane may be called the **duct** (L. *ductus*, aqueduct). It carries off the gastric juice secreted by the rest of the gland, and is lined by simple columnar epithelium, which also covers that part of the mucous membrane which lies between the glands.

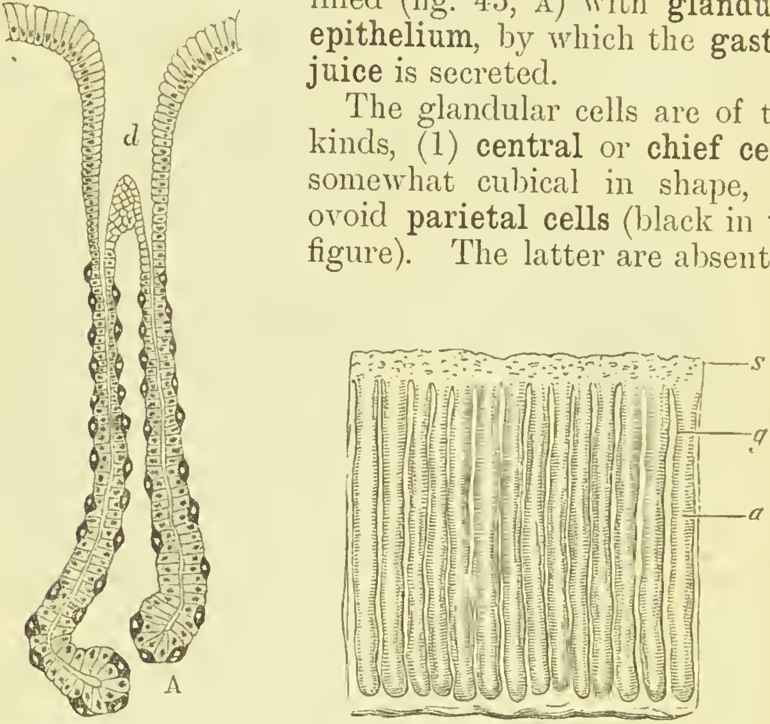


Fig. 43.—The Mucous Membrane of the Stomach in section, highly magnified.

s points to the surface, *g* to one of the tubular glands, of which *a* indicates the central canal. A is a much more highly magnified view of one gland, which is represented as giving off branches. It shows the columnar epithelium of the surface dipping down into the duct *d* of the gland, from which two tubes branch off. Each tube is lined with squarish cells, and there is a minute central passage. Here and there are seen other special cells (coloured black in figure) called parietal cells, which are supposed to produce the acid of the gastric juice.

At the junction of stomach and duodenum a **pyloric sphincter** is formed by a special thickening of the circular muscle layer. It projects inwards as a sort of circular ridge, forming a valve known as the **pylorus** (Gk. *pulōrŏs*, gatekeeper) because it guards the opening between stomach and intestine.

The **gullet** is constructed on the same plan as stomach and intestine, but differs in the following points:—(1) There is no serous coat; (2) The well-developed muscular coat consists of red or voluntary muscle in its upper part; (3) The epithelium which lines the mucous membrane is **stratified** (L. *stratum*, layer) **epithelium**, consisting of several layers of cells, which become more and more flattened as the surface is approached (cp. fig. 44).

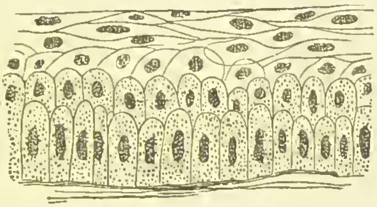


Fig. 44.—Stratified Squamous Epithelium. [Klein.]

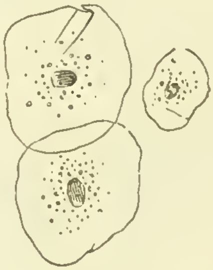


Fig. 45.—Isolated Cells of Squamous Epithelium.

The **pharynx** resembles the upper part of the gullet in structure, and the mucous membrane of the **mouth** is also lined by stratified epithelium, of which some detached cells are represented in fig. 45. The dark area in the centre of each cell represents the nucleus.

The glands so far described are all minute and imbedded in the mucous membrane. There are, however, a number of large glands, which have arisen as outgrowths of the alimentary canal, and now lie entirely outside it, pouring their secretions into it by special ducts. These glands are the salivary glands opening into the mouth, liver and pancreas opening into the duodenum.

There are three pairs of **salivary glands**, all situated in the head and secreting the saliva or spittle. The largest pair are the **parotid glands** (Gk. *para*, beside; *ous*, *ōtŏs*, ear), situated below the skin in front of the ear (fig. 46, P P′), and sending a duct (*d*) forwards to open into the side of the mouth. The **submaxillary glands** (L. *sub*, below; *maxilla*, jaw) lie below and within the back of the lower jaw (*sm*). Their ducts run forwards and open close together on the floor of the mouth on a small elevation situated not far behind the middle incisors. The **sublingual glands** (L. *sub*, below; *lingua*, tongue) are less than half the size of the preceding. They lie, one on each side, in a ridge which runs along the front part of the floor of the mouth between the tongue and teeth. Each possesses a number of ducts, of which the largest opens near that of the submaxillary duct, while others open into that duct, and the remainder on the surface of the ridge.

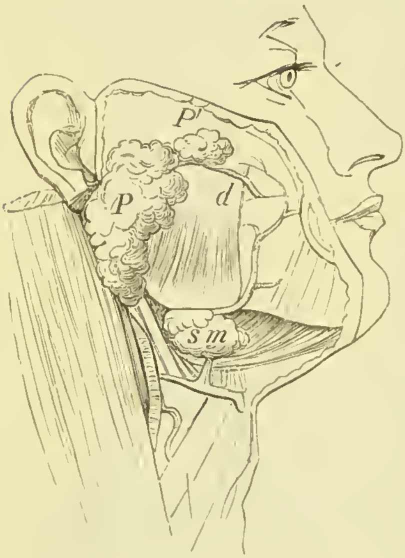


Fig. 46.—The Salivary Glands.

P P′, Parotid; *sm*, submaxillary. *d* is placed below the duct of the parotid.

The **structure** of the salivary glands can be understood by reference to fig. 47. A simple tubular gland is represented by 1; 4 and 5 possess little pouch-like outgrowths, and are said to be *sacculated* (L. *sacculus*, little bag); while 6 is still further complicated, having undergone *branching*. This last kind is termed *racemose* (L. *racemus*, bunch of grapes), because there is a vague resemblance to a bunch of grapes.

A salivary gland consists of a large number of small rounded **lobules** (diminutive of lobe) each of which has the structure represented in 6, and the main duct is formed by the union of smaller ducts from these lobules, just as a river is formed by the union of tributaries.

The entire gland is lined by simple epithelium, made up in the pouches or **alveoli** (L. *alveolus*, a small receptacle) of the lobules of large cells which secrete the saliva. The lobules and ducts are bound together by a framework of connective tissue traversed by blood-vessels and nerves.

The **liver** is an exceedingly large gland, of a reddish-brown colour, situated in the upper part of the abdomen (fig. 3), where its convex upper surface fits closely against the diaphragm, and its irregular somewhat concave lower surface rests on the stomach, part of the intestines, and other organs. It weighs about 3½ lbs., and measures about 11 inches from side to side, 6 to 7 inches from front to back, and 3½ inches from above downwards in its thickest part, which is to the right. The liver is divided into *right* and *left lobes*, which are of very unequal size, the former being much the larger of the two. When turned up (fig. 48) a pear-shaped bag, the **gall-bladder** (*g*) is seen firmly attached to the middle of the right lobe. By the union of a duct from each lobe, an **hepatic duct** (G. *hēpar*, liver) is formed (fig. 38), which

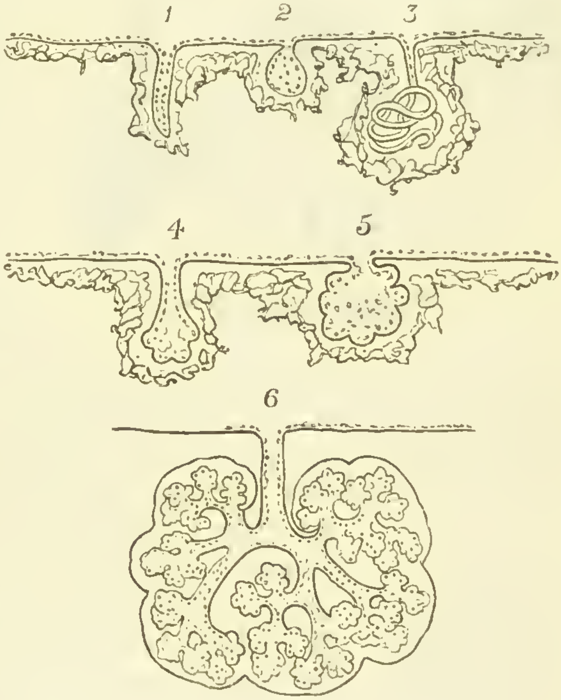


Fig. 47.—Diagram of the Structure of Secreting Glands.

The continuous line represents the outer boundary of the connective tissue of mucous membrane. The dotted line represents the position of the epithelium. The irregular line shows the position of the blood-vessels. 1 shows the simple tubular gland. 2 indicates how the mouth may become shut and a sac formed. 3 represents a coiled tube. 4 and 5 indicate the formation of recesses to produce a sacculated gland, and 6 is a plan of part of a racemose gland. [Sharpey.]

receives the **cystic duct** (Gk. *custos*, bag) from the gall-bladder, and later on unites with the **pancreatic duct** to form the **common bile-duct**, which opens into the duodenum three or four inches beyond the pylorus.

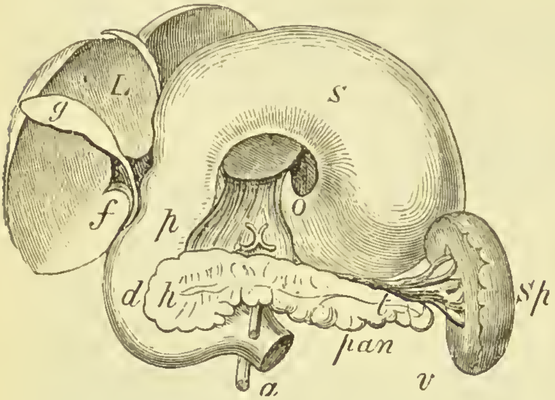


Fig. 48.—Relations of the Stomach to the Liver, Pancreas, and Spleen.

Structure of the Liver.—The liver consists of an enormous number of minute lobules, which can be seen with a lens on a cut surface as polygonal areas from $\frac{1}{12}$ to $\frac{1}{24}$ of an inch broad. Each of these lobules again consists, as may be made out by means of the microscope, of a very large number of **liver-cells** (fig. 49), which must be regarded as having the nature of glandular epithelium. Between these cells the finest branches of the hepatic ducts unite together as a delicate network. It is a condition even more complicated than the one represented in fig. 47, 6. Imagine a minute very much branched tube lined with epithelium, then suppose the branches to unite into a network, and a rough idea will be gained of the nature of a liver lobule. This accords, too, with the facts of development, for the liver is, to begin with, a simple pouch growing out of the duodenum. As in the case of other organs, the liver is supported by a connective tissue framework traversed by blood-vessels, nerves, &c.

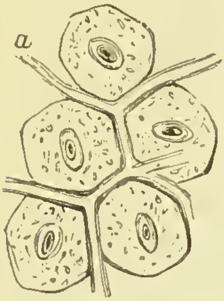


Fig. 49.—Cells of the Liver (very much magnified), with channels (*a*) for the bile between.

The **pancreas** or **sweetbread** is a reddish yellow lobulated gland about 7 inches long and $1\frac{1}{2}$ inches average breadth, which can be seen running across the back of the abdominal cavity when the stomach is lifted up (fig. 48). The *head*, or broad right-hand end of the pancreas (*h*) occupies the loop of the duodenum, while its narrow left-hand end or *tail* touches the **spleen** (*sp*), a flat, oval body, reddish in colour, and attached to the cardiac end of the stomach. The **pancreatic duct**, formed by union of smaller ducts from the various lobules, runs for the most part in the substance of the gland, and finally joins the hepatic duct (fig. 38). In structure the pancreas closely resembles a salivary gland.

CHAPTER IV.

DIGESTION AND ABSORPTION.

The structure of the digestive organs and the nature of food having been treated in some detail, we may now consider what actually takes place in the alimentary canal during digestion.

Digestion in the Mouth.—Here the food undergoes chewing or mastication, and is mixed with the saliva, which not only softens, and thus makes it more easy to break down, but also exerts a very important chemical action. The sharp edges of the incisors divide the food, while the irregular crowns of the grinding teeth work against each other like millstones. During the chewing process both cheeks and tongue assist in mixing up the food and keeping it between the teeth. The lower jaw is so articulated that it can move in various ways, of which only the up and down movements need further consideration here. It is *raised* mainly by the action of two muscles, the temporal and masseter. The **temporal muscle** is somewhat fan-shaped, and takes origin from the surface of the temporal bone. It narrows below, runs down the inner side of the zygomatic arch, and is inserted into the coronoid process partly by means of a tendon and partly directly. This muscle can be seen and felt contracting in the temple every time the jaw is raised. The **masseter** is a squarish muscle arising from the zygomatic arch and inserted into the outer side of the ramus of the lower jaw, where its contractions can easily be detected by sight or touch. Part of this muscle can be seen in fig. 46. The lower jaw acts as a lever of the third class (p. 44) when it is being pulled up, the fulcrum being at the joint, the power being supplied by the muscles described, and the weight being that of the lower jaw together with the resistance to chewing presented by the food. The *downward* movement of the lower jaw is partly the result of its own weight and partly due to muscular action, the most important muscle concerned being the **digastric** (Gk. *dis*, twice; *gastēr*, belly). This has an elongated form, and consists of a fleshy portion or belly at each end and a tendon in the middle. The posterior end of the muscle takes origin from the temporal bone not far from the occipital condyle, and the anterior end is inserted into the under side of the chin, while the tendon is fixed to the hyoid bone.

Saliva, the secretion of which is greatly increased by the presence of food in the mouth, is a turbid, glairy, alkaline fluid which consists almost entirely of water, with only about ½ per cent of solid matter. By far its most important constituent is an organic substance known as **ptyalin** (Gr. *ptualŏn*, spittle), which is present in only very minute quantity and possesses the remarkable power of converting starch into sugar—not the article of ordinary use, but a kind known as **maltose**, because present in malt. This may easily be proved by keeping a small quantity of starch paste in the mouth for a short time, when it will be found to acquire a sweet taste. The chemical process that goes on is a kind of **fermentation**: which name is applied to cases where certain complex bodies known as **ferments**, in this case ptyalin, bring about chemical change without being at the same time appreciably used up. Hence a small amount of ferment can go on acting for a very long time, which is a matter of great convenience in physiological work. The action of saliva can be studied outside the body, and two important facts established thereby: (1) starch is digested by it more rapidly at the temperature of the body than at a lower one; (2) *boiled* saliva has no effect on starch, the ptyalin being destroyed by a high temperature. Saliva has practically no action on proteids and fats, but some of the mineral salts dissolve in it, as does any sugar which may be present. It must be remembered that the object of digestion is to dissolve the food as far as possible; hence the importance of the **amylolytic** (Gk. *amulŏn*, starch; *lŭtikŏs*, able to break up) **ferment** ptyalin, which converts practically insoluble starch into readily soluble sugar.

Swallowing or **Deglutition** (L. *deglutio*, I swallow). This is the mechanical process by which food passes from the mouth through the pharynx and gullet to the stomach. It is much facilitated by the softening and moistening action exerted by the saliva. In swallowing, and the subsequent passage of the food through stomach and intestines, the muscular coat is the active agent, especially the circular layer of fibres, which is better developed than the longitudinal layer. It is clear that contraction of the former will narrow the cavity of the alimentary canal, and this contraction takes place in a wave-like manner, so that the food is gradually squeezed onwards. This kind of movement is known as the **peristaltic action** (Gk. *pĕristaltikŏs*, clasping and compressing). The longitudinal layer does not contract at the same time as the circular layer, and its exact use is not clearly understood, but its contraction in any part of the digestive tube would undoubtedly shorten and broaden that part. After, therefore, a given region has been narrowed by the circular layer it would probably be enlarged again by the longitudinal layer.

The first and voluntary part of swallowing carries the food back on the upper side of the tongue to the beginning of the pharynx, and now begins the second part of the process, over which the will has no control, and which consists in a gradual squeezing of the food downwards by peristaltic action. It must clearly be understood that the food does not (except, as a rule, in the case of liquids) simply *fall* down into the stomach, for swallowing can be effected when the body is placed head downwards, and grazing animals habitually swallow upwards. During the passage of the food through the pharynx it is important that none of it should get into the posterior nares or glottis. The former contingency is guarded against by the soft palate, which is pulled upwards and backwards so as to touch the back wall of the pharynx, while food is prevented from passing down into the windpipe by the epiglottis, which is bent back so as to cover the glottis and form a bridge over which the food can pass. These arrangements are sometimes upset;—on the one hand, a sudden fit of coughing may force food up into the nasal cavities, on the other, an attempt to speak during eating may cause the epiglottis to spring up and fragments to pass into the glottis. The expression 'going the wrong way' is familiarly applied to the latter phenomenon.

Digestion in the Stomach.—The movements produced by the muscular layers are here much more complicated. To begin with, the food undergoes a gentle 'churning' movement until it is reduced to a greyish pulp, the **chyme** (Gr. *chumos*, pulp). As digestion proceeds peristaltic movements proper take place in the pyloric end of the stomach, by which successive portions of chyme are squeezed into the duodenum, the pyloric sphincter relaxing so as to allow of this. Nothing but pulpy material, however, is allowed to pass on, for the contact of large fragments causes the sphincter to contract again. The presence of food in the stomach leads to a flow of blood to the mucous membrane and to the secretion of considerable quantities of **gastric juice**. This is a clear acid fluid containing a very small percentage of dissolved solids. The acidity is due to the presence of $\frac{1}{10}$ per cent of hydrochloric acid (HCl), and the most important of the dissolved solids are two ferments, pepsin and rennin. The acid is believed to be secreted by the parietal cells of the gastric glands and the ferments by the central cells (p. 66). **Pepsin** (Gk. *pĕptō*, I digest) possesses the important property of being able to convert proteids into a soluble form termed **peptone.** **Rennin** is a milk-curdling ferment, that is to say, it converts the proteid substance **casein** (L. *caseus*, cheese), which is dissolved in milk, into a solid form, this 'curd' being then digested by the pepsin. Gastric juice is only of importance in so far as it digests proteids in virtue of its pepsin, which, from the nature of its action, is termed **proteolytic ferment** (*proteid*, Gk. *lutikŏs*, able to break up). The ptyalin carried down into the stomach being only able to work in an alkaline solution, first of all ceases to act on starch, and is then destroyed by the acid of the gastric juice.

Digestion in the Intestine.—The acid chyme, coming over into the intestine from the stomach, is gradually moved on by peristaltic action, and is subject to the action of bile, pancreatic juice, and intestinal juice. Digestion is practically completed by the time the end of the small intestine is reached.

Bile or **Gall** is an alkaline fluid of golden red colour, and consisting of 86 per cent of water, with 14 per cent of other constituents, of which certain complex organic compounds known as **bile-salts** make up the greater part. Digestion is aided in several ways by this secretion. It neutralizes and so stops the action of the gastric juice which comes with the chyme into the intestine, and in this way assists the pancreatic juice. On starch and proteids bile has no action, but it helps to emulsify fats and oils, *i.e.* to break them down into very small globules. Besides this, it has an antiseptic action, preventing the contents of the intestine from becoming putrid.

Pancreatic juice is a much more important secretion. It is a clear alkaline fluid containing about 3½ per cent of dissolved solids, including three different ferments, which act respectively on starch, proteids, and fats. The first of the ferments, **amylopsin** (Gk. *amulŏn*, starch; *ŏpŏs*, juice), acts in the same way as ptyalin, while the second, **trypsin** (Gk. *thrupsis*, dissolving), behaves like pepsin, except that it is much more powerful, and can only act in an alkaline solution. The remaining ferment, **steapsin**, causes part of the fats to break down into soluble substances. Besides this, pancreatic juice in conjunction with bile converts a good deal of the fat into an emulsion known as **chyle** (Gk. *chulŏs*, juice). This is a milky fluid in which innumerable minute globules of fat are suspended. It may be noted here that milk itself is a kind of natural emulsion.

Intestinal juice has a feeble digestive action, but comparatively little is definitely known about it.

ABSORPTION OF DIGESTED FOOD.

The digestion of the food is followed by its absorption into the blood-vessels and certain other tubes, lacteals, which ramify in the mucous membrane.

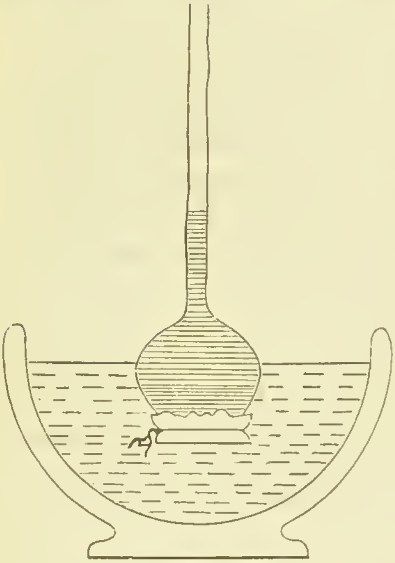


Fig. 50.—Dialyser.

In the case of the parts of the food which are reduced to solution, the process is one of **diffusion** (L. *diffusus*, spread out), a term used to signify the mixing which takes place when two liquids or two gases are in direct contact with one another, or else are separated by a porous partition or a moist membrane. Fig. 50 represents a simple piece of apparatus, called a **dialyser** (Gk. *dia*, through; *lusis*, setting free), by which diffusion of the last kind can be demonstrated. A piece of bladder or vegetable parchment is tied on to a thistle funnel, which is then partly filled with a mixture of treacle and water, and immersed in a vessel of water, so that the levels of the inside and outside fluids are the same. After a short time, the treacle will rise in the stalk of the funnel (fig. 50), and the outside water will acquire a sweet taste. There has in fact been a passage or diffusion through the membrane in both directions, but more water has passed in than treacle out. Underneath the epithelium of stomach and intestine there is a close network of very minute blood-vessels (capillaries), which may be compared to the funnel in fig. 50, while the blood in them corresponds to the treacle. The delicate walls of these vessels, plus the epithelium, answer to the moist membrane, while the dissolved contents of the digestive tube are equivalent to the water in the outer vessel. The importance of converting insoluble non-diffusible starch and proteid into soluble, diffusible sugar and peptone will now be realized. Absorption of digested food begins in the stomach and ends in the large intestine, but is mainly carried on in the small intestine. This part of the digestive tube offers an enormous absorptive surface, as a result of its great length and the presence of innumerable villi. Two villi are drawn diagrammatically in fig. 51, and in the one on the right the network of blood-vessels is shown.

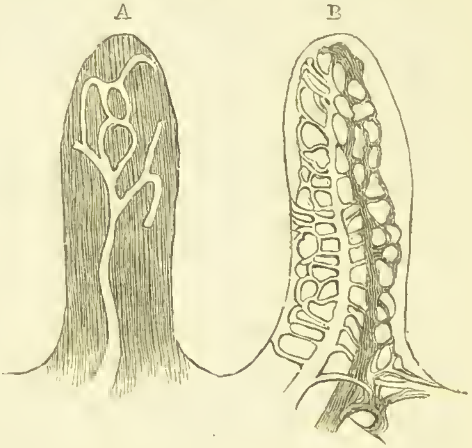


Fig. 51.—Villi greatly magnified.

A, Showing lacteal; B, showing artery, capillaries, and vein.

The emulsified fats do not diffuse in the proper sense of the word, but the minute globules, of which they are composed, make their way, how is not fully known, into minute branched tubes, one of which is contained in each villus (fig. 51, A). These tubes are known as the **lacteal rootlets**, because they are the beginnings, as it were, of the **lacteals**, tubes distinct from the blood-vessels, which ramify in the mucous membrane and mesentery (cp. chap. V.). The name lacteal (L. *lac*, milk) is given because, after a meal into which fat largely enters, they have been seen to contain a milky fluid, chyle. This chiefly consists of the digested fats.

Different Varieties of Diet.—It has been calculated that an adult man of average weight requires 300 grains of nitrogen and 4500 grains of carbon in every day's food. The other necessary elements can be for the present left out of consideration. There are three chief ways of getting the quantities required: (1) by a pure proteid diet, (2) by a vegetable diet, (3) by a mixed diet.

(1) **Proteid Diet.**—Supposing a man tries to live on nothing but fairly lean cooked meat. This contains about 22 per cent proteid matter and 7 per cent fat. About half of the former is carbon and $\frac{3}{20}$ nitrogen. The fat contains 80 per cent carbon. Working this out, a pound (7000 grains) of cooked meat contains 1162 grains of carbon and 231 grains of nitrogen. To get the requisite 4500 grains of carbon, it would therefore be necessary to eat about 3 lbs. 4 oz. of the meat. This, however, would contain 1126 grains of nitrogen, *i.e.* 895 more than are required. The digestion and excretion of this unnecessary nitrogen would throw a large amount of useless work on the organs concerned.

PERCENTAGE COMPOSITION OF VARIOUS FOOD-STUFFS.

	Water.	Nitrogenous.	Starch.	Sugar.	Fat.	Salts.
Bread, ...	37	8·1	47·4	3·6	1·6	2·3
Wheat-flour, ...	15	10·8	66·3	4·2	2·0	1·7
Oatmeal, ...	15	12·6	58·4	5·4	5·6	3·0
Potatoes, ...	75	2·1	18·8	3·2	0·2	0·7
Rice, ...	13	6·3	79·1	0·4	0·7	0·5
Peas, ...	15	23·0	55·4	2·0	2·1	2·5
Cow's milk, ...	86	4·1	...	5·2	3·9	0·8
Cheese, ...	36·8	33·5	...	...	24·3	5·4
Fairly lean cooked meat, ...	66	22·0	...	...	7·0	5·0
Egg, ...	74	14·0	...	...	10·5	1·5

(2) In considering the possibilities of a **vegetable diet,** oatmeal porridge (without milk) may be taken as an example, for it contains a good deal of proteid matter, and this is the only source from which the requisite nitrogen can be obtained. The following are the data necessary for the calculation:

Oatmeal contains 12 per cent of proteids, 63 per cent of carbohydrates, and 5 per cent of fat. Proteids contain 50 per cent C and 15 per cent N; carbohydrates contain 40 per cent C, and fats 80 per cent C. A pound (7000 grains) of dry oatmeal will therefore yield 2464 grains C, but only 126 grains N. To get the 300 grains of N it would therefore be necessary to make 2⅖ lbs. of dry oatmeal into porridge for the day's food. This would give, in round numbers, 1500 grains of carbon too much. A similar objection to the one given under (1) would therefore apply here also.

Oatmeal, however, is a very favourable example of vegetable food. If potatoes were taken, 13½ lbs. would be required daily to make up the necessary quantity of nitrogen.

(3) A **mixed diet** obviates the disadvantage mentioned above, enabling the necessary amount of carbon and nitrogen to be gained without excess of either. For example, 2 lbs. of bread, together with ¾ lb. of cooked meat, would be a sufficient daily ration, and contain no excess of either carbon or nitrogen. Besides this, a mixed diet is found to be more digestible, more appetizing, and more economical.

Average Mixed Diet.—The average amount required daily by an adult has been estimated as follows:—

		oz. avoirdupois.	
In dry state.	Proteids,	4½	=46 oz. of food in the ordinary moist condition + 2½ pints of water taken as liquid.
	Fat,	3	
	Carbohydrates,	14¼	
	Salts,	1	
	Water,	3¾ pints.	

It must be remembered that the majority of the articles used as food are themselves of mixed nature.

Salts, for example, are contained in meat, bread, vegetables, and most drinking water, so that it will only be necessary in the case of a rational mixed diet to supplement this amount by using ordinary table salt. This will be clearly apprehended from the table on p. 78.

CHAPTER V.

CIRCULATORY ORGANS AND CIRCULATION.

The Circulatory Organs, which have already been briefly referred to (p. 15), consist of the Blood System and the Lymph System, named respectively from the liquids they contain.

The **Blood System** is a closed set of tubes through which the blood circulates, and these tubes are subdivided into (1) the **heart**, acting as a force pump, (2) **arteries**, vessels in which the blood is going *from* the heart, (3) **veins**, vessels in which the blood is going *to* or towards the heart, and (4) **capillaries**, excessively minute vessels forming networks between the smallest branches of the arteries and veins. It is of the greatest importance to notice that the arteries and veins, having comparatively thick walls, are of use only as carriers of blood, for no diffusion can take place through their walls. It is far otherwise with the capillaries, the walls of which are exceedingly thin, so that diffusion can take place through them in both directions. Thus, as previously explained, most of the products of digestion diffuse *into* the capillaries underlying the epithelium of the stomach and intestines. Similarly, as will be shown in the sequel, oxygen gas diffuses *into* the capillaries of the lungs. Again, in the various tissues of the body, the muscles, for example, products of waste diffuse *into* these minute tubes. On the other hand, we get diffusion *out of* the capillaries (1) of nutritive substances to the various tissues for use in their repair and growth, or in the preparation of secretions, (2) of waste products to the excretory organs.

The **Lymph System** contains a clear fluid, the **lymph,** which fills the large cavities of the body, *e.g.* the body cavity, and also the minute chinks and spaces which occur in all the tissues. It consequently bathes these tissues and acts as a medium between them and the blood contained in the capillaries, for it must be remembered that the tissues are *outside* the capillaries. Imagine a fine-grained piece of wet sponge and imbedded in it a number of small parchment-walled tubes containing liquid. The sponge will roughly represent a piece of tissue, the water permeating it lymph, the tubes capillaries, and the liquid contained in them blood. Diffusion can take place through the walls of the tubes in both directions, just as is the case with capillaries. Lymph, however, is not entirely contained in irregular spaces, but also in narrow tubes, the **lymphatics,** which drain these spaces. The lacteals already mentioned (p. 77) are examples of these tubes. The lymphatics ultimately open into the blood-system.

THE BLOOD SYSTEM.

The **blood,** which constitutes about $\frac{1}{13}$ of the total body weight, consists of an alkaline fluid, the **plasma** (Gk. for anything formed), and of a vast number of microscopic bodies, the **blood corpuscles,** suspended in it. These corpuscles are of two kinds, red, to which the colour of the blood is due, and colourless or white. A magnified drop of blood is represented in fig. 52. The **red corpuscles** are there seen to be circular discs rather thinner in the middle which causes them to appear dark there when viewed flatways. In shed blood they are apt to stick together like piles of coin. One of these corpuscles is only $\frac{1}{3200}$ of an inch broad, *i.e.* 3200 of them placed side by side would only extend an inch. The greatest thickness is about a quarter the breadth. There are about 12 lbs. of blood in an average body, and this quantity will contain some thirty billion red corpuscles. If these were placed side by side with their edges touching, they would extend, in round numbers, 150,000 miles, or, in other words, six times round the earth. A red corpuscle appears yellowish under the microscope, as does a thin layer of blood to the naked eye, the familiar red colour being due to the passage of light through a large number of corpuscles. A distinction is drawn between the framework or **stroma** (Gk. for anything spread out) of the corpuscle and the substance **hæmoglobin** (Gk. *haima*, blood; *globin*, a kind of proteid) which permeates the stroma, and is the cause of the red colour. Both components are of proteid nature. Hæmoglobin is of very great importance, since it acts as an oxygen-carrier.

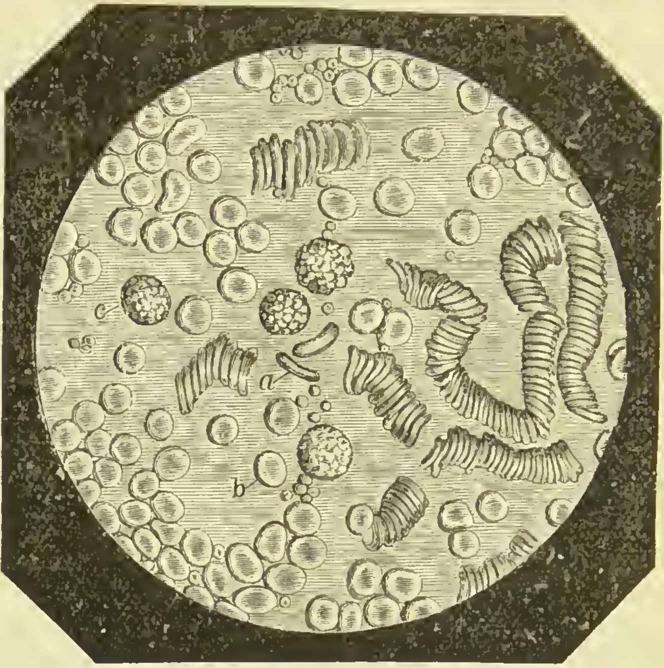


Fig. 52.—A Drop of Blood, seen under a Microscope magnifying 350 diameters.

a, Red corpuscle seen edgeways; *b*, do. seen flatways; *c*, white corpuscle.

The **colourless** or **white corpuscles**, often termed **leucocytes** (Gk. *leukŏs*, clear; *kutis*, small box), are rather larger than the red corpuscles, being on an average $\frac{1}{2500}$ of an inch in diameter. They are also less numerous than the red, in the proportion of 1 to 350. In shed blood, allowed to cool below the temperature of the body, they appear as irregular spheres, but when in the body, or even out of it if kept warm, they exhibit a constant change of shape, and are able to creep along by thrusting out blunt prolongations (fig. 53). Leucocytes consist of protoplasm, and contain a nucleus (cp. p. 64), not shown, however, in the accompanying figures.

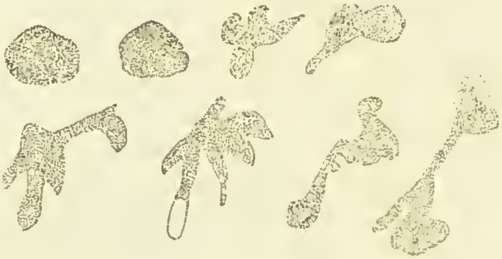


Fig. 53.—White Blood Corpuscle. Its successive changes of shape.

Blood plasma has a very variable composition, as will readily be understood from what has already been said (p. 80). It contains nutritive substances derived from the digested food, and waste products derived from the tissues. The latter will be discussed elsewhere.

One of the most remarkable powers possessed by blood is that of **clotting** or **coagulation**, which is a matter of the greatest practical importance in stopping the bleeding from cuts, &c. If some human blood is shed from the body into a cup or other suitable vessel, it is to begin with quite fluid, but in two or three minutes becomes viscid, and from five to ten minutes later sets into a jelly. A few minutes subsequent to this drops of a pale yellowish fluid begin to exude from the jelly, and this process continues until in from one to several hours, the blood has completely coagulated, and consists of a red **clot** floating in a pale yellow fluid, the **serum** (L. for whey). Examination of a small portion of the clot under the microscope shows that it consists of innumerable delicate fibres interlacing in all directions and binding the corpuscles into a firm mass. These fibres consist of a proteid which, from the manner of its occurrence, is termed **fibrin**, and which is not present in uncoagulated blood. The following table shows the relation between the two kinds of blood:—

Ordinary Blood. { plasma { serum
fibrin } clot } **Coagulated Blood.**
corpuscles }

Formation of Fibrin.—This question is by no means fully understood, but fibrin appears to arise as a result of ferment action (p. 72) exerted by a proteid known as **fibrin ferment** on another proteid **fibrinogen** (fibrin; Gk. *gĕnnaō*, I produce) present in the plasma. The leucocytes play some part in the matter, probably having to do with the formation of fibrin ferment. When blood coagulates fibrin is produced from fibrinogen by the action of the fibrin ferment. Its fibres then shrink, squeezing out the serum, but entangling the corpuscles. If fresh drawn blood is 'whipped' with a feather or bundle of twigs, the formation of fibrin will be hastened, and it will adhere to the twigs as formed, the 'whipped blood' left behind consisting of corpuscles + serum.

Coagulation is hastened or retarded by various conditions, of which the most important are the following:—

Hastened by	**Retarded by**
1. Contact with foreign bodies, *e.g.* when whipped with twigs.	1. Contact with living walls of vessels. This prevents it altogether.
2. Heating to 102°—131° F.	2. Cooling to freezing point or heating to 133° F.
	3. Addition of various substances, *e.g.* common salt.

The **Heart** is a hollow muscle, bluntly conical in shape, and situated in the thorax between the lungs with its apex directed downwards and to the left (fig. 54). The lower end of the heart rests on the upper side of the diaphragm, and it is mainly kept in position by the large blood-vessels which enter or leave its broad upper end or base. The weight of the heart is about 9 or 10 oz., and its size roughly equivalent to the fist of the individual. It is contained in a membranous bag, the **pericardium** (Gk. *pĕri*, round; *kardia*, heart), the wall of which consists of an inner layer closely investing the heart and a much firmer outer layer. Between the two is a **pericardial space** filled with clear lymph known as the **pericardial fluid.**

"A good idea of the pericardium will be obtained if one takes two thin paper bags, of which one is slightly smaller than the other, so that one may be contained within the other, both being fully distended. Now slightly fold back the edge of the mouth of the inner bag and gum it all round to the edge of the mouth of

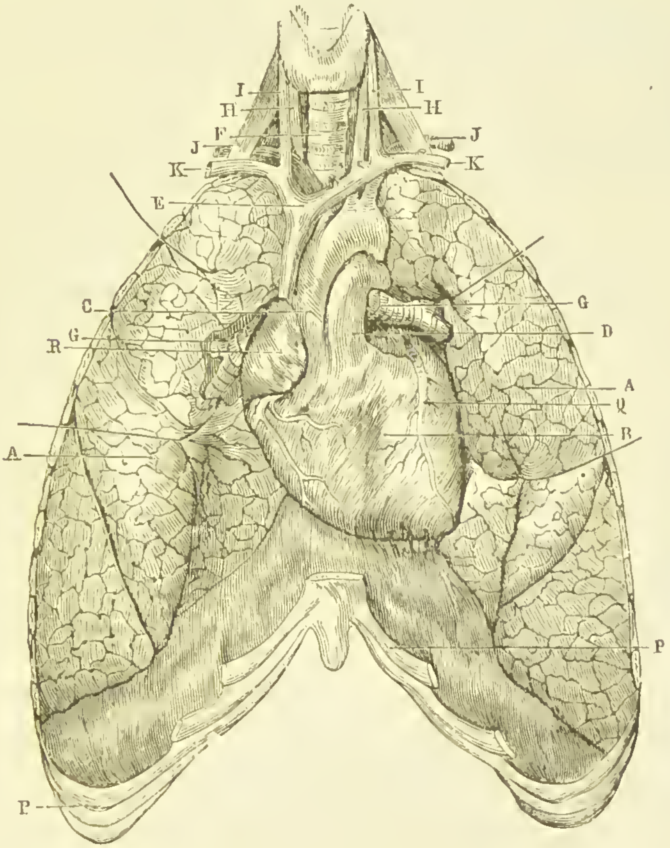


Fig. 54.—The Heart with its Blood-vessels and the Lungs.

A, The lungs pulled aside in front to show the heart, B, and the bronchi, G, G; C, the aorta; D, the pulmonary artery; E, the superior vena cava, formed by the junction of the veins (subclavian) from the right and left sides, K, K; F, the windpipe; I, I, veins from the head and neck (jugular) joining K, K; H, H, arteries (carotid) to head and neck; J, J, arteries (subclavian) passing to right and left sides; P, P, ribs; Q, left coronary artery; R, right auricle.

the outer one. There is now made a double bag with an inner and an outer layer, and a small space between them, completely shut off from the outside. Suppose the closed fist to be just large enough to fill the inner bag, it will represent the heart, to which the inner layer of the pericardium is adherent. The wrist will represent the great vessels passing off from the heart, around which the neck of the double bag extends."—*M'Gregor-Robertson.*

The heart does not contain one continuous cavity, but four chambers—right and left **auricles**, and right and left **ventricles**. The relative position of these is indicated by the accompanying diagram (fig. 55), which shows that the heart is divided into (1) right and left halves by a longitudinal partition, and (2) basal and apical halves by a transverse partition. Four chambers are thus constituted; but while the longitudinal partition is quite complete, so that *there is no direct communication between right and left halves*, the transverse partition has a hole (auriculo-ventricular opening) in it on each side, so that the right and left auricles respectively communicate with the right and left ventricles, as indicated by the arrows. The wall of the heart is chiefly made up of bundles of muscular fibres arranged in a very complex manner, but chiefly taking an oblique direction. When they contract the contained cavities are diminished in size (cf. p. 73) and the blood squeezed out of them. The walls of the different chambers are not of the same thickness (figs. 55 and 60), but are proportionate to the work that has to be done in each case. The **auricles**, which occupy the base of the heart, are so named (L. *auricula*, little ear) because to each of them a little flap is attached

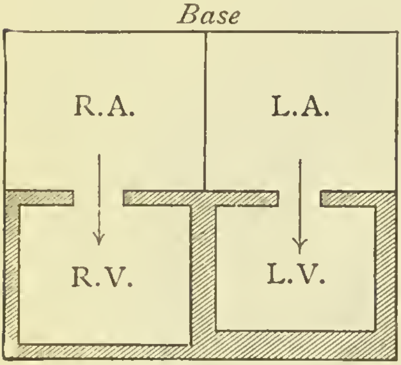


Fig. 55.—Diagram of Auricles and Ventricles.

(fig. 57) which has been compared to a dog's ear. Their walls are comparatively thin, and collapse when the heart is taken out of the body, unless special precautions are taken to prevent it. The function of the auricles is to *receive* blood from certain veins and squeeze it into the corresponding ventricles. Their walls are thin because this work is comparatively light. The **ventricles** (L. *ventriculus*, little belly) receive blood from the auricles and pump it out of the heart into certain arteries. This being severer work than that done by the auricles, their walls are thicker; and since the left ventricle has the harder work to do, its walls are thicker than those of the right ventricle (figs. 55 and 60).

These preliminaries being understood, further details will now be given, it being also remembered that **veins** carry blood *to* the heart, and **arteries** carry blood *from* it. Besides this the terms *pure* and *impure* blood require explanation. **Impure blood** is that coming from the body at large, to the tissues of which it has given up much of its oxygen, while in return it has received from them carbon dioxide (CO_2), as well as other waste products which need not be considered in this connection. **Pure blood** is that which comes from the lungs, where it has got rid of its excess of CO_2 and absorbed its full amount of oxygen. Impure blood is bluish violet, pure blood bright scarlet in colour. In popular language the terms *venous* and *arterial* are often used instead of impure and pure, veins and arteries being defined in a corresponding way as vessels containing impure and pure blood respectively. This in the main accords with the facts of human physiology; but as *some* veins contain pure blood and *some* arteries impure blood, it is best to drop the terms venous and arterial altogether, and to define veins and arteries with reference to the direction of blood-flow in them. If this is not done the beginner is sure to be confused more or less. In figs. A–D the parts containing impure blood are coloured purple, and those containing pure blood are coloured red. It will be seen at a glance that the right side of the heart contains nothing but impure and the left side nothing but pure blood.

External Characters of the Heart (fig. B). At the base are seen the large veins which enter the auricles and the large arteries which leave the ventricles. (1) **Veins.** Two large veins, the **superior** and **inferior vena cava** (L. for upper and lower empty veins), return the impure blood of the body to the right auricle, and four much smaller **pulmonary veins** (L. *pulmo*, lung) return pure blood from the lungs into the left auricle. (2) **Arteries.** The large **pulmonary artery** opens out of the right ventricle and carries its impure blood to the lungs, while the pure blood from the left ventricle is carried off by the **aorta** (Gk. *aĕirō*, I carry), which is the largest artery in the body. A groove marks off the auricles from the ventricles, and the boundary between right and left ventricles is also indicated by a groove. The front or ventral side of the heart, shown in fig. 57, can be distinguished by the fact that the aorta and pulmonary artery begin there, while the inferior cava and pulmonary veins open into the dorsal side or back. The easiest way of distinguishing right and left is to notice that the walls of the *right* ventricle are comparatively soft, while the *left* ventricle extends into the extreme apex of the heart (compare figs. B and 60) and the aorta curves round to the *left* (fig. B).

Interior of the Heart (figs. C, D, and 60).—When the **right auricle** is cut open two large and one smaller openings *into* it and one large opening *out* of it can be distinguished. The two large openings into it are those of the superior and inferior vena cava, the latter being guarded (see fig. D) by a crescentic flap, the **Eustachian valve.** Just below this is the smaller opening (not shown in the figure), that of the **coronary sinus**, which is guarded by a membranous fold, the **Thebesian valve.** The large opening out of the auricle is the **right auriculo-ventricular opening**, leading into the right ventricle.

There are two openings in the wall of the **right ven-**

Fig. A

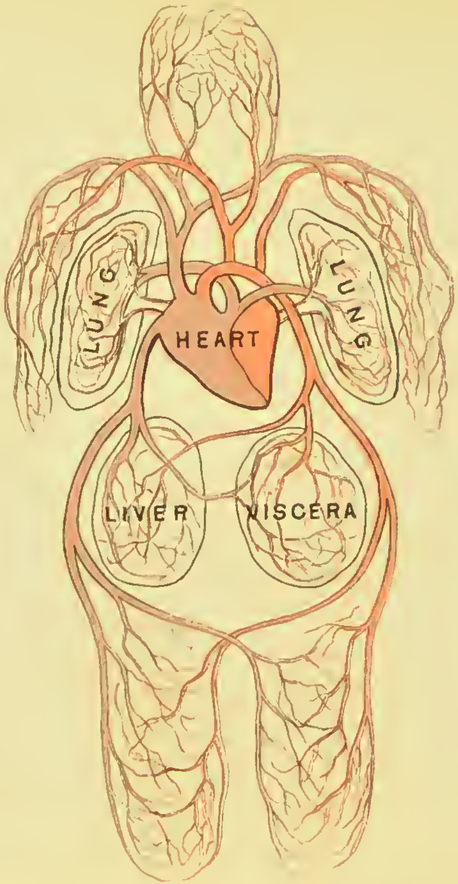
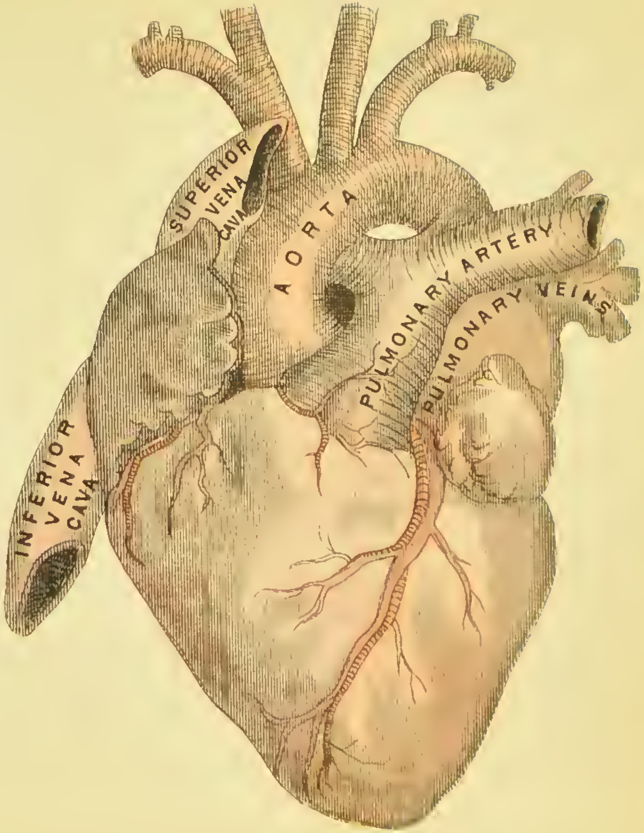


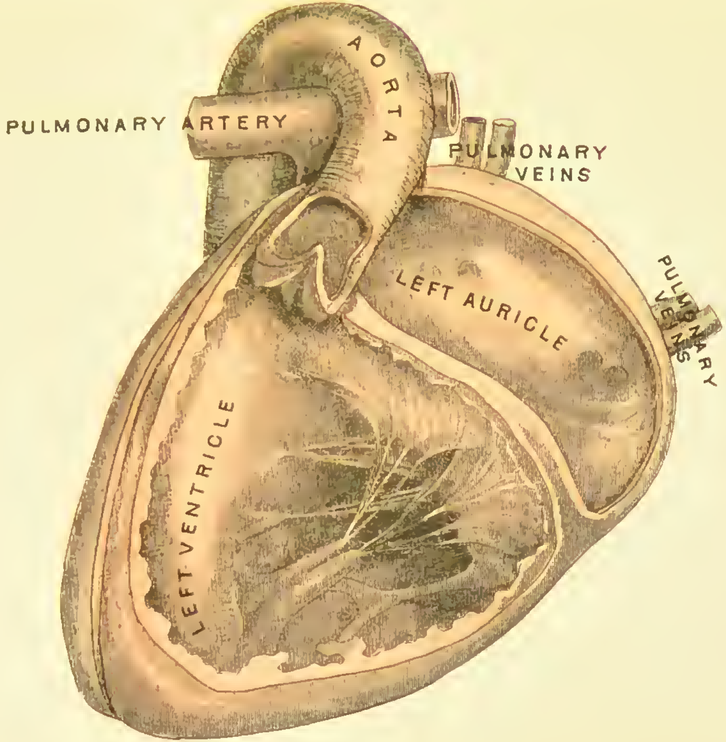
DIAGRAM SHOWING THE CIRCULATION OF THE BLOOD

Fig. B.



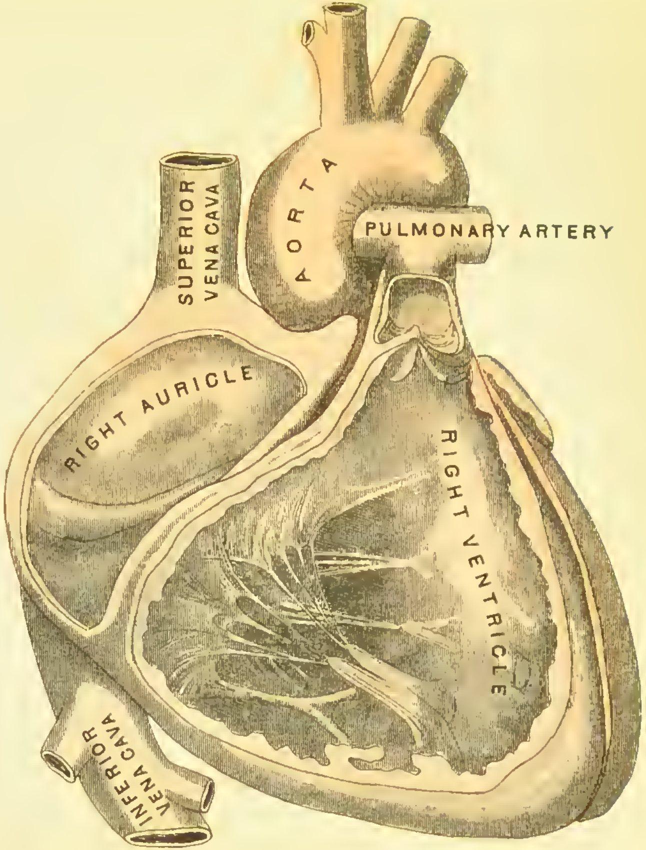
EXTERNAL VIEW OF HEART FROM FRONT

Fig. C.



LEFT SECTION OF HEART

Fig D



RIGHT SECTION OF HEART.

tricle, the one just mentioned as opening into it, and the opening of the pulmonary artery out of it. Both are guarded by valves which secure the flow of blood in one direction only. That belonging to the auriculo-ventricular opening is termed the **tricuspid valve** (L. *tres*, three; *cuspis*, point) because it consists of three firm membranous flaps, triangular in shape, which are attached to the fibrous margin of the orifice and project into the ventricle. When the ventricle contracts, these flaps (previously floated up by the blood) are driven towards one another, so as to prevent the blood from flowing back into the auricle. The flaps would, however, be forced back into the auricle by the pressure of the blood if there were not a further arrangement to prevent it. The inner wall of the ventricle presents a number of fleshy projections (the **columnæ carneæ** = L. for fleshy columns), some of which, the **papillary muscles**, are conical or cylindrical in shape and stick out into the cavity of the ventricle. Numerous exceedingly tough fibrous cords (**chordæ tendineæ** = L. for tendinous cords), resembling tendons in nature, run from the papillary muscles to the flaps of the valve and

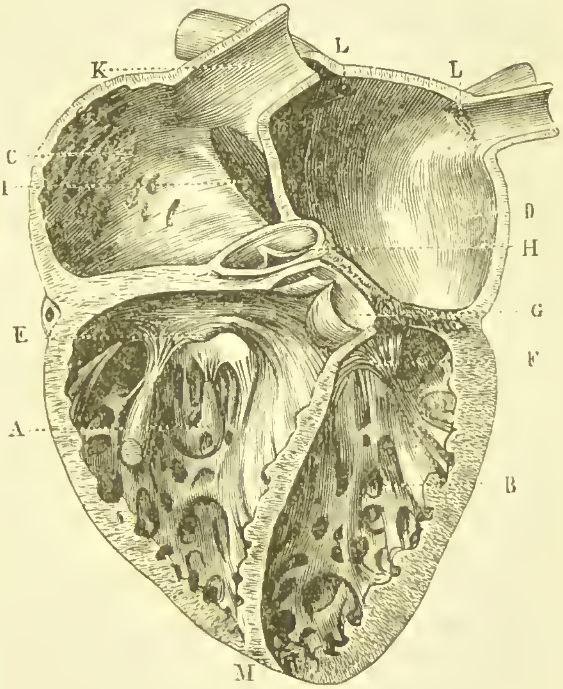


Fig. 60.—The Heart opened from the front to show its Chambers.

A and B, Right and left ventricles; C and D, right and left auricles; E, tricuspid, and F, mitral valves; G, pulmonary artery; H, aorta; I, orifice of inferior vena cava; K, superior vena cava; L, L, orifices of pulmonary veins; M, termination of longitudinal septum; P, papillary muscle.

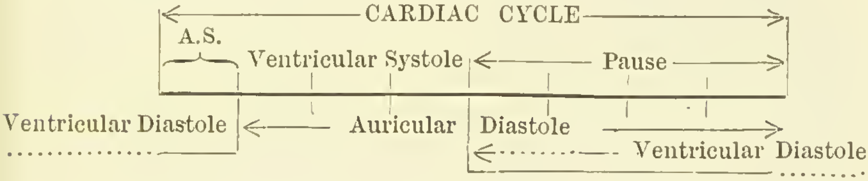
prevent them from being driven into the auricle. The action of the papillary muscles is not fully understood, but they probably contract before the rest of the ventricular wall and commence the closure of the valve by drawing the flaps together.

The **semilunar valves** at the origin of the pulmonary artery allow the blood to flow out of the ventricle, but prevent its return. They are three little firm membranous pouches (best seen in fig. 60), often called 'watch-pocket' valves, because they resemble in shape the watch-pockets often seen fastened up in bed-rooms for holding a watch at night. The cavities of these pouches are turned *towards* the cavity of the artery. When blood passes out of the ventricle they collapse and offer no resistance, but when blood tries to force its way back into the ventricle they are bulged out so as to meet one another and stop the passage. But three curved pouches like these would still leave a minute aperture in the middle, if it were not for three little thickenings, one of which is situated on the edge of each pouch, just at its centre.

Within the **left auricle** will be noted the four small openings of the pulmonary veins *into* the cavity, and leading out of it the **left auriculo-ventricular opening**, which is rather smaller than the right. The interior of the **left ventricle** resembles in many respects that of the right ventricle, there being one aperture into and one out of it, but the left auriculo-ventricular valve is guarded by *two* flaps only, hence the name **bicuspid**, or else **mitral valve**, from a fancied resemblance to a bishop's mitre. The origin of the aorta is guarded by three semilunar or watch-pocket valves similar to those already described. These and the mitral valve act in the same way as the corresponding structures on the right side of the heart.

The action of the heart involves a regularly recurring series of events which together make up what is termed a **cardiac revolution** or **cycle**, or 'beat', occupying in an average adult $\frac{4}{5}$ of a second, *i.e.* the heart beating 75 times a minute. First of all the short **auricular systole**

(Gk. *sustĕllō*, I contract) occurs, the two auricles contracting together and squeezing their blood into the ventricles, then follows the longer **ventricular systole**, during which the ventricles pump blood into the pulmonary artery and aorta—and, lastly, comes a still longer **pause.** While the auricles are contracting, and during the pause, the ventricles are relaxing, and similarly the auricles are relaxing while the ventricles are contracting, and during the pause. The term **diastole** (Gk. *di*, apart; *stĕllō*, I place) is applied to this relaxation. The relation in time of these events for an average cardiac cycle may conveniently be expressed by the following diagram, where the eight divisions of the line are equivalent to tenths of a second. (A.S. = auricular systole.)



Thus during the *first* tenth of a second the ventricles are finishing up a relaxation commenced in the previous cycle (indicated by dotted line to left), then they contract for $\frac{3}{10}$ of a second, and then begin a period of relaxation which ends during the next cycle (as indicated by the dotted line to right). It further appears that the auricles rest for $\frac{7}{8}$ their time and the ventricles for $\frac{5}{8}$. It must not be supposed that blood enters the ventricles *only* during the auricular systole: it flows into them during the pause as well. In other words, blood is passing from auricles into ventricles, *except* during the ventricular systole, at which time the tricuspid and mitral valves are closed. The semilunar valves are only open during the last two-thirds of the ventricular systole.

The contraction of the heart, and more particularly of the ventricles, causes it to be jerked upwards and forwards so that during the ventricular systole its apex is projected against the wall of the chest, between the fifth and sixth ribs on the left side. This phenomenon is known as the **cardiac impulse**, or 'beating' of the heart. Besides this, the contraction of the heart is accompanied by **sounds**, which can be heard through a stethoscope applied to the chest. There is (1) a **long dull sound**, heard during the contraction of the ventricles, and (2) after a brief pause a **short sharp sound**, immediately following their contraction. Muscles give out sounds when contracting, and the first sound is probably in part such a 'muscular sound', due to contraction of the walls of the ventricles. It may, however, be partly due to vibration of the flaps of the tricuspid and mitral valves. The second sound is undoubtedly due to the closure of the semilunar valves.

Work of the Heart.—It is usual to estimate work in **foot-pounds**, a foot-pound being the work done in raising a pound through the distance of a foot. Measured in this way an average heart, during twenty-four hours, does an amount of work equal to that required to raise an average adult (weighing 154 lbs.) to a height of $\frac{1}{3}$ of a mile—*i.e.* about 268,800 foot-pounds. Three-quarters of this work is done by the left ventricle.

BLOOD-VESSELS AND COURSE OF THE CIRCULATION.

It will already have been realized from the last few pages that the heart is so constructed as to allow the blood to flow in one direction only. When the auricles contract the blood does not flow back into the veins but into the ventricles, because this is the easier course. When the ventricles contract the tricuspid and mitral valves close so that the blood cannot flow back into the auricles, and is therefore forced into the pulmonary artery and aorta. It is prevented by the semilunar valves from returning to the ventricles.

Course of the Circulation (fig. 56).—It will now be convenient to trace the course of the blood when it leaves the heart. The impure blood received by the **right ventricle** from the right auricle is pumped into the

pulmonary artery, which divides into two branches, one for each lung. These branches divide repeatedly into smaller and smaller arteries, which at last open into the network of **capillaries** by which the lungs are permeated. In these capillaries the blood is purified, and then flows into minute veins which unite into larger and larger trunks till at last the four **pulmonary veins** are reached, which open into the **left auricle**. That part of the circulation, so far described, is often known as the **lesser**, or **pulmonary circulation**.

The pure blood entering the **left auricle** passes on into the **left ventricle** and thence into the **aorta**, which conveys it to all parts of the body except the lungs. The curved beginning of the aorta (*arch of the aorta*) gives off branches to the heart itself (*coronary arteries*), to the neck and head (*carotid arteries*), and to the upper limbs (*subclavian arteries*) (fig. 54). The rest of it, known from its position as the *dorsal aorta*, runs just in front of the backbone through thorax and abdomen, giving off numerous branches in its course. In the lower part of the abdomen the aorta divides into two *iliac arteries* for the lower limbs (fig. 71). All the branches of the aorta divide and redivide into smaller and smaller arteries till **capillaries** are reached. In these capillaries the blood becomes impure and then passes into minute veins, which, by their repeated union, originate trunks of larger and larger size. Finally the blood enters the veins which open into the right auricle. These are (1) the **coronary sinus**, formed by the union of branches from the wall of the heart itself, (2) the **superior vena cava**, formed by union of veins from the head, neck, and upper limbs, and (3) the **inferior vena cava**, made up of tributary veins from the trunk and lower limbs. The last vein is the largest in the body. In the abdomen it runs along the right side of the aorta, but in the thorax it is situated a little distance in front of it. That part of the blood system just described is often termed the **greater** or **systemic circulation**. Two subordinate parts of it require further notice, *i.e.* those constituting the coronary and portal systems.

Coronary System.—The large amount of work done by the heart renders it specially necessary that arrangements should be made for supplying it with pure and nourishing blood, and for carrying away its waste products. The heart is not able, as might be supposed, to absorb the necessary amount of nutritious material and oxygen from the blood contained within it, nor can all its waste products make their way into that blood.

Two **coronary arteries**, coming off from the very beginning of the aorta, branch up in the walls of the heart and supply them with blood, while their waste products are carried off by **coronary veins**, the most important of which unite to form the **coronary sinus**. The shortest course by which any portion of blood can pass from the left to the right side of the heart is by means of the coronary vessels. (These vessels are seen branching on surface of heart in fig. 57.)

Portal System.—The veins which carry away the blood from the stomach, intestines, pancreas, and spleen unite together into a large trunk known as the **portal vein**. This, instead of opening into a still larger vein, runs to the liver and breaks up into smaller veins which divide repeatedly in the tissues of that organ, ultimately communicating with its capillaries. From these capillaries small veins again begin, and by their union give rise to two or three large **hepatic veins**, which open into the inferior vena cava. The longest course by which a portion of blood can pass from the left to the right side of the heart is through the portal system. The liver is not only supplied with impure blood by means of the portal vein, but also with pure blood by means of the hepatic artery, which comes off from a branch of the aorta. The question naturally arises—why should the blood from the digestive organs go through the liver? In answering this question it must be remembered that this blood contains all the products of digestion except the digested fat, and it appears that the liver takes up and stores the digested carbohydrates for the use of the body, dealing them out again as required.

Structure of Blood-vessels.—Arteries and veins have been so far regarded as vessels carrying blood from and to the heart respectively, the portal vein being an exception in so far that it breaks up again into small veins in the substance of the liver. Capillaries have been defined as exceedingly small vessels intervening between the smallest arteries and the smallest veins. The structural differences between these three kinds of blood-vessel may now be considered. **Capillaries**, which it is convenient to consider first, make up networks (cp. fig. 51) with meshes of various sizes and shapes in all parts of the body except the epidermis (including hair and nails) epithelium, teeth, and cartilage. The name capillary (L. *capillus*, hair) is rather an unfortunate one, as these vessels are very much smaller than hairs, being not more than from $\frac{1}{3500}$ to $\frac{1}{2000}$ of an inch in diameter. The smallest therefore will only allow the red corpuscles to squeeze through them in single file. The exceedingly thin walls of capillaries are made up of **simple squamous epithelium**, *i.e.* a single layer of flattened epithelial cells (fig. 61). A small **artery** (fig. 62) will not only be much larger than a capillary, but its walls will be much thicker and composed of several coats. These are: (1) a lining layer of epithelium (*a*) like that of the capillary walls; (2) an elastic membrane; (3)

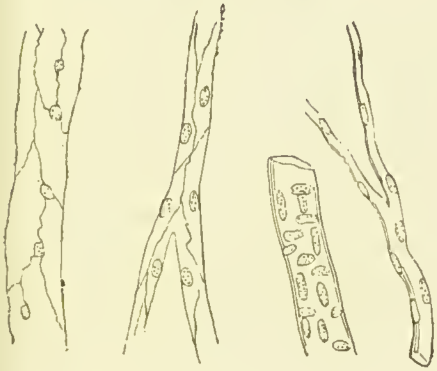


Fig. 61.—The Structure of Capillaries.

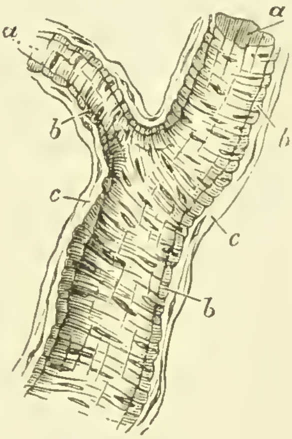


Fig. 62.—Structure of an Artery.

layer of involuntary muscle (*b*) consisting of fibres running in a circular direction; (4) a layer (*c*) of fibrous connective tissue. A small **vein** will possess the same layers, but its walls will be thinner, as the elastic and muscular parts of it are not so well developed as in an artery. The difference between the large veins and arteries will be still more marked. In dissecting such an animal as a rabbit or cat, the difference between the thin-walled veins and the thick-walled arteries is very apparent. The former will be full of blood, while the latter are pale and almost empty since at death their muscular walls contract and force out the blood into the veins. Another important distinction is that veins are provided with valves here and there during their course, while arteries are not. These valves are pouch-like folds of the veins which act in much the same way as the semilunar valves, and prevent the blood from flowing back away from the heart. These valves can easily be demonstrated in any one of the long blue veins which can be seen running from the hand along the front of the forearm. If a finger tip is firmly pressed on one of these and carried along it towards the hand, a little swelling will arise at some point in the vein in front of the finger tip. This swelling marks the position of a valve. The pressure of the finger has, in fact, been forcing the blood the wrong way, and closed the valve, so that the vein is made to swell up by pressure of the blood unable to pass it. Each of the valves usually consists of two pouches. In comparing small arteries with large, the former are distinguished by the relatively large amount of muscle in their walls, and the latter by the abundance of their elastic tissue.

Character of the Circulation in the Blood-vessels.—Owing to the difference in size and structure between the different kinds of blood-vessel, and to the different position which these have as regards the heart; it is not to be expected that blood should flow through them in exactly the same way. **Arteries** are nearer the heart than the other vessels, and when one of them is cut, the blood comes out in spurts which correspond to the beats of the heart. **Veins**, on the other hand, are furthest from the heart, and it is therefore not surprising that when one of them is cut the blood should flow out continuously and more slowly.

These last-mentioned facts are of great practical importance, as in case of an injury severing a blood-vessel, they enable one to determine whether it is an artery or vein. In the former case the bleeding may be stopped by applying pressure on the *heart-side* of the injury, and in the latter by applying it on the side *away* from the heart. The **rate of flow** depends partly upon the nearness to the heart, and partly upon the amount of friction offered by the walls of the blood-vessels. In a large artery, such as the carotid of a dog, the blood may flow at the rate of from 12 to 20 inches per second, but as the arteries divide again and again the rate gradually diminishes, just as a river runs more slowly when it breaks up into a number of channels or broadens into a lake. In the smallest arteries the flow is probably only a small fraction of an inch per second. The **capillaries** present a very great resistance to the passage of blood, for to force liquid through them is almost like forcing it through a piece of sponge, and the rate of flow is estimated at rather less than 2 inches per minute. As the blood begins to pass from the capillaries into the small veins, its pace quickens, and finally in the largest veins, such, for example, as the jugular of the dog, it reaches the rate of some 8 inches per second.

Proofs of the Circulation.—The structure of the heart and the presence of valves in the veins are enough in themselves to prove that blood circulates through the blood-system in the direction that has already been described. Injection of coloured liquids into the vessels of dead bodies also proves that the heart and blood-vessels are adapted for conducting blood by a particular course. But in addition to this, the circulation of the blood can be easily demonstrated in the living body. The best means of doing this is to observe the transparent web of a frog's foot under a low power of the microscope. Here the blood can actually be seen flowing from small arteries into capillaries, and from capillaries into veins. The arteries can be easily recognized, because in them the blood always flows from larger to smaller branches, while the contrary is true for the veins. It is also noticeable that the red corpuscles (here very large, oval, and nucleated) keep, where possible, in the centre of the stream, while the white corpuscles roll along the walls of the vessels on the margins of the stream. Another proof of the circulation is found in the facts already given about the flow of blood from cut arteries and veins. To this may be added that soluble substances, injected into a blood-vessel or absorbed from the alimentary canal, soon make their way all over the system.

The **elasticity** of the arteries, especially the large ones, plays an important part in the circulation. If with an india-rubber syringe, used to represent the heart, water is forced by a series of strokes into a tube with inelastic walls, say a glass or lead tube, it will flow out at the other end in jerks, and this will happen even if the resistance is increased by plugging the end of the tube with a piece of sponge. The same transmission in jerks will happen if an india-rubber tube is substituted, unless the resistance is increased by blocking its end with sponge or in some other manner. In that case the tube will swell up with each stroke of the syringe, and there will be a steady flow of water from its far end. In fact, the force of each stroke is partly expended in driving the water forwards and partly in dilating the tube, while before the next stroke, the elastic wall of the tube will return to its former condition, driving on the liquid as it does so. Exactly the same kind of thing happens in the case of the elastic arteries.

When the ventricles contract, part of the force goes to expand their walls, which recoil again during the ventricular diastole, and continue the pumping work. The blood therefore flows with a fairly even current, instead

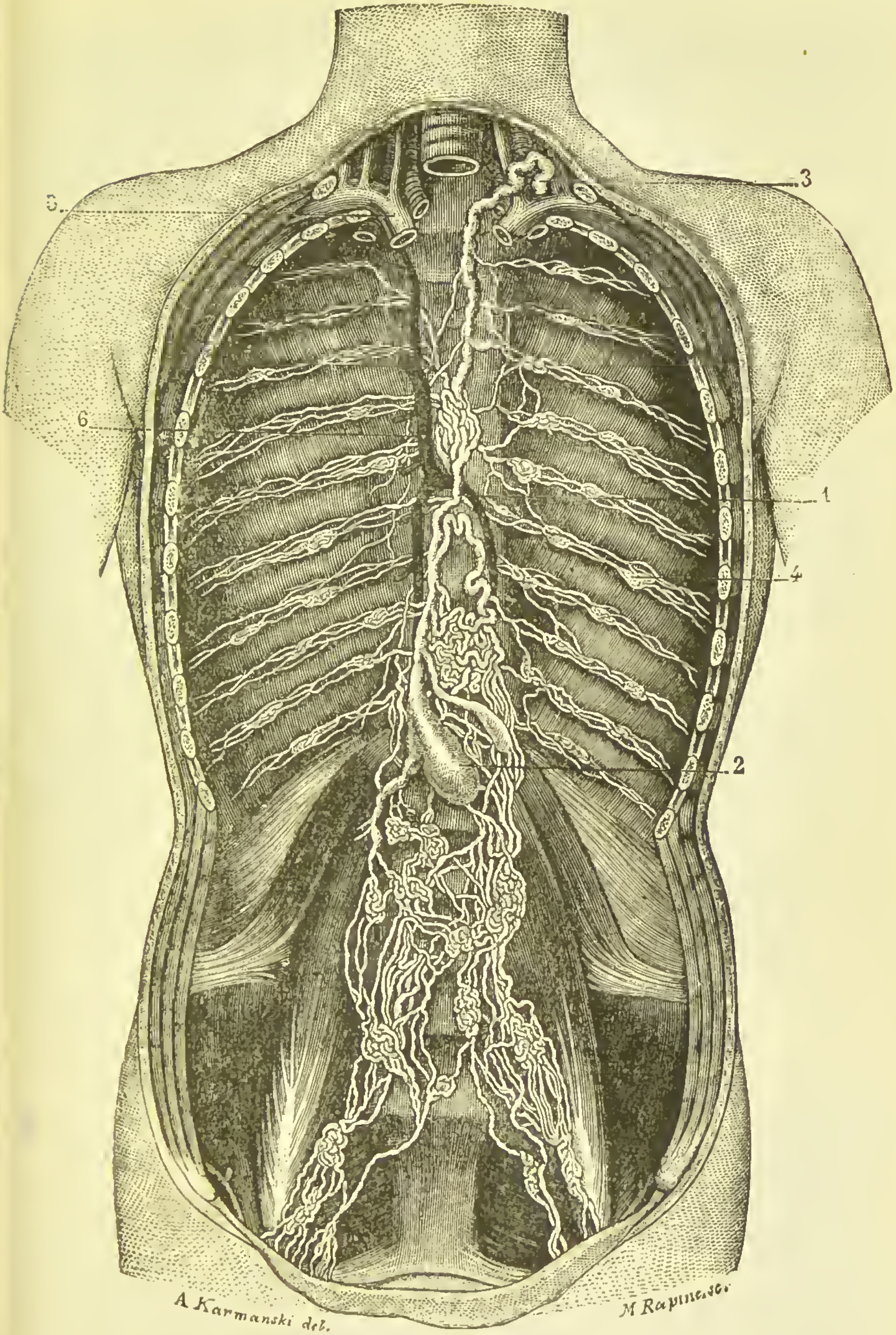


Fig. 63.—The Thoracic Duct and Lymphatic Vessels.

of being propelled in a series of jerks, as would be the case if the walls of the arteries were inelastic. What is known as the **pulse** simply consists of the alternate expansion and recoil of the elastic walls of the arteries, as the ventricles alternately contract and relax.

The **muscular layer** in the walls of the arteries, especially of the smaller ones, serves another purpose: that of regulating their size. The fibres of this layer run in a circular way, so that when they contract the artery is narrowed. Their state of contraction is regulated by certain nerves, known from their function as **vaso-motor** (L. *vas*, vessel; *motor*, mover) **nerves**. Under ordinary circumstances these fibres are in a tonic or half-contracted state, but they can be made to contract more or to contract less, as a result of which the artery is narrowed or widened respectively. In this way the amount of blood supplied to the different parts of the body is regulated.

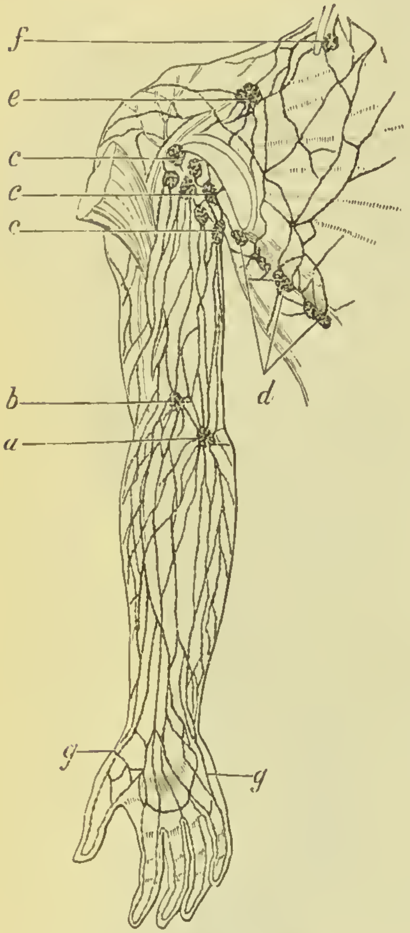


Fig. 64.—Lymphatics of the Arm and Arm-pit.

Glands at the inner side of the elbow *a*, *b*, in the arm-pit *c*, *c*, *c*, on the chest in front of the arm-pit *d*, above the collar-bone and communicating with the arm-pit *e*, *f*, *g*, *g* point to lymphatic vessels forming an arch round the hand. The dark lines are lymphatic vessels.

LYMPHATIC SYSTEM.

It is not necessary for the elementary student to know much more about this system than has already been explained on pp. 77 and 81. The **lacteals**, which belong to the intestine and carry away the digested fats from it, run in the mesentery, and ultimately enter the lower end of the **thoracic duct** (figs. 63, 213), a tube about as thick as a crow-quill, which lies along the front of the backbone, from the second lumbar vertebra to the base of the neck, and opens into the left subclavian vein (near 3). Nearly all parts of the body are traversed by **lymphatics**, which are quite similar to the lacteals in structure, and for the most part open into the thoracic duct (4). Both lacteals and ordinary lymphatics resemble small veins in structure, and contain numerous valves. Unlike veins, however, they remain of about the same size in all parts of their course, and here and there they traverse small swellings (fig. 64) known as **lymphatic**, or in the case of the lacteals, as **mesenteric glands**. These are not glands in the sense already defined (p. 64), and since they possess no ducts, are often called 'ductless glands'. Their function is to produce new leucocytes.

The **spleen** (fig. 48) is usually reckoned to belong to the lymphatic system, and is another example of a 'ductless gland'. Its duty appears to be that of destroying used up red corpuscles which are no longer fit to circulate in the blood-vessels.

CHAPTER VI.

RESPIRATORY ORGANS AND RESPIRATION.

The physiological meaning of breathing or respiration has already been briefly explained (p. 15) as the means by which the blood maintains its supply of oxygen, and gets rid of its excess of carbon dioxide, together with a great deal of water. The **lungs** are two red spongy bodies, which together weigh about 2½ lbs. in the adult, and fill during life the greater part of the cavity of the thorax, one on each side of the heart (fig. 54). Each lung is somewhat conical in shape, with a blunt apex above and a concave base below, where it fits against the diaphragm. The other side is convex, and fits closely against the wall of the thorax, while the inner side is concave in correspondence with the convex shape of the heart. The left lung is divided into upper and lower lobes, and the right lung into upper, middle, and lower lobes. Just as the heart is suspended in the thorax by the great blood-vessels at its base, being free elsewhere, so is each lung suspended by the large blood-vessels which enter and leave it, and by one of the two branches of the windpipe (**bronchi**, fig. 65, B, C). All these structures are attached to what is known as the 'root' of the lung, situated rather above the middle of its inner side. Except at their roots, the lungs are quite free. It has been explained that the heart is contained in a double bag, the pericardium (p. 85), and in the same way each lung is contained in a similar bag, called in this case the **pleura** (Gk. *pleura*, side). The outer layer of each pleura lines its half of the thorax much as the peritoneum lines the abdomen, abuts against one side of the pericardium, and, where not separated by the heart, comes into contact with the corresponding layer of the other pleura. The inner layer of the pleura closely invests the lung, at the root of which it becomes continuous with the outer layer. During life the two layers are in close contact, but there is a small amount of lymph between them, so that they are kept moist, and can easily glide over one another during the movements of breathing.

The **windpipe** or **trachea** (fig. 65, A), by which air is carried to and from the lungs, is a tube rather less than an inch broad, which runs down the front of the neck into the upper part of the thorax, where it forks into two smaller tubes, the **bronchi** (Gk. *brŏnchŏs*, windpipe), one for each lung (B, C). The top of the windpipe is much enlarged, and constitutes the **larynx**, or organ of voice, into which the glottis (p.) opens. The larynx is supported by several cartilages, of which the largest is the **thyroid cartilage** (Gk. *thureŏs*, shield; *eidŏs*, resemblance), constituting the projection, specially large in men, known as 'Adam's apple'. Below this comes a ring-shaped **cricoid cartilage** (Gk. *krikŏs*, ring; *eidŏs*), broad behind and narrow in front. The windpipe can easily be felt along the front of the neck as a firm tube with a wall raised up into ridges, which have earned for it the name trachea (Gk. *trachus*, rough). These ridges are due to the presence of hoops of cartilage, by which its walls are supported in front and at the sides, and which prevent it from collapsing, which would interfere with breathing. The back of the windpipe, however, where it abuts upon the gullet, is soft and membranous, so that it does not interfere with swallowing. The walls of the bronchi are stiffened in the same way. If either the right or left bronchus is followed into its lung, it

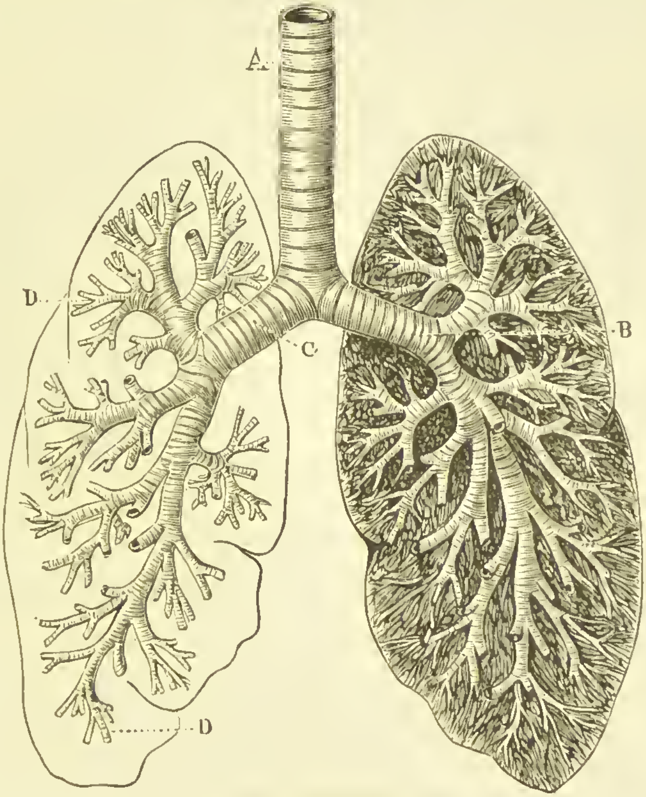


Fig. 65.—Bronchial Tubes.

will be found (fig. 65) to branch repeatedly into **bronchial tubes** (D), the smallest of which are about $\frac{1}{50}$ of an inch in diameter. The larger tubes have their walls stiffened by pieces of cartilage, but this is not the case with the smallest branches, the walls of which are delicate and membranous. If one of these smallest bronchial tubes is followed up, it will be found to end blindly in a group of air-sacs (fig. 66) much wider than itself. The wall of each air-sac is raised into a large number of rounded projections known as **air-cells** (*b*). If the surface of the lung is examined carefully, it will be found to present a mottled appearance, due to its division into an immense number of minute lobules varying from $\frac{1}{4}$ to $\frac{1}{2}$ an inch in diameter. Each of these lobules consists of a number of groups of air-sacs, bound together by connective tissue.

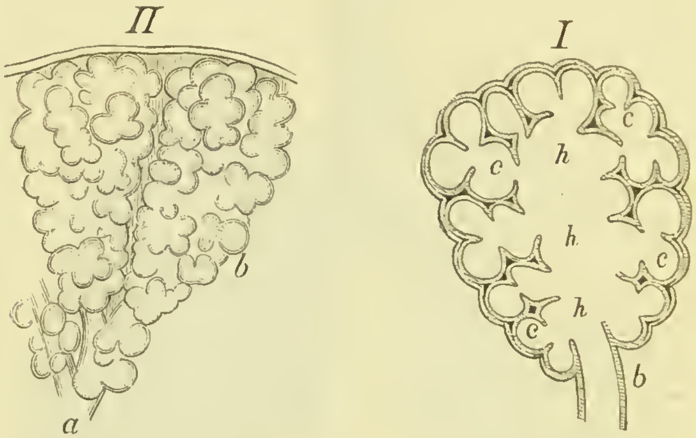


Fig. 66.—Air-cells of the Lung.

II. A couple of air-sacs connected with one of the smallest bronchial tubes (*a*). I. Air-sac in section; *h*, *h*, *h*, central cavity; *c*, *c*, *c*, *c*, cavities of air-cells; *b*, one of smallest bronchial tubes.

The complicated arrangement of branching tubes, of which the lungs mainly consist, is lined throughout by mucous membrane covered by epithelium. In the trachea, bronchi, and bronchial tubes the epithelium is mainly composed of columnar cells, placed at right angles to the surface, and covered on their free ends by short threads (about $\frac{1}{3000}$ of an inch long) of protoplasm, known as **cilia** (L. *cilium*, eyelash) (fig. 67). Each cilium possesses the power of contractility, but this is not shown, as in the case of a muscle-fibre, by shortening with equivalent thickening, but by alternate bending and straightening in a very regular manner. The cilia which line the air-passages all work together in such a way as to sweep mucus and foreign particles towards the glottis. They constitute, in fact, an arrangement by which the air-passages are kept clean. This is a matter of very great importance, as all sorts of solid impurities are being constantly taken in with the air that is breathed. The epithelium, which lines the air-sacs, is simple and squamous, consisting of a single delicate layer of flattened cells. Immediately outside this layer are situated the capillaries of the lungs as a very close network.

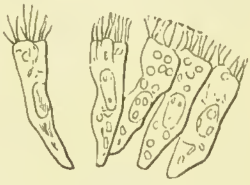


Fig. 67.—Cells of Ciliated Epithelium.

Movements of Respiration.—It has already been explained (p. 31) how, by the movements of the ribs and sternum the size of the chest can be increased from side to side and from before backwards. The **diaphragm**, which forms the floor of the chest, is also capable of movements which increase its size from top to bottom. The centre of the diaphragm is of the nature of a tendon, and remains almost at rest below the heart during breathing, but its margins are made up of muscle, which, when it contracts, flattens out, so as to increase the capacity of the chest. This process is aided by two muscular masses known as **pillars of the diaphragm**, which run from its dorsal region to the front side of the lumbar vertebrae. During **inspiration** the ribs and sternum move upwards and forwards, and at the same time the diaphragm contracts, so that the dimensions of the chest are increased in all three directions. During **expiration**, the ribs and sternum move downwards and backwards, and the diaphragm ceases to contract, becoming convex again. In this way the dimensions of the chest diminish in all directions. The lungs contain a great deal of elastic connective tissue, which, during life, is always kept on the stretch, so that the lungs are, as it were, constantly trying to contract. If in a freshly killed rabbit the abdomen is carefully opened and the liver pulled back, the pink lungs will be seen through the transparent diaphragm fitting closely against the wall of the thorax. If now the diaphragm is punctured on one side, the lung on that side will shrink to a comparatively small size, in virtue of its elasticity. The uninjured thorax may be regarded as an air-tight box, and the lungs are kept expanded by the pressure of the air in the air-passages. They could not shrink away from the wall of the thorax without causing a vacuum between the two layers of the pleuræ, and their elasticity is not sufficiently powerful to effect this. When, however, the wall of the thorax is injured, the pressure in the air-passages is neutralized by a corresponding pressure on the outside of the lung concerned, its elasticity comes into play, and it consequently shrinks. From what has been said, it follows that when the capacity of the chest is increased by movement of its walls, the lungs must enlarge to a corresponding extent, and air must at the same time enter them. The lungs diminish in size as a matter of course when the chest does so, and air consequently passes out of them.

Air can pass in and out of the lungs either by way of the mouth or of the nose, both of which courses can be understood from fig. 34. The inward course in the former case is — mouth-opening—mouth—pharynx—glottis; in the latter—nostrils—nasal cavities—posterior nares—pharynx—glottis. The outward course is the same as the preceding read the other way round. Breathing through the nose is more natural and more desirable than breathing through the mouth. The average **rate of breathing** in the adult is about 17 times a minute, about 30 cubic inches of **tidal air** passing in and out each time. As after an ordinary inspiration the lungs contain 230 cubic inches of air, it will easily be realized that the tidal air only passes in and out of the larger air-passages, an arrangement by which injury of the more delicate parts of the lung is guarded against. If a very full breath is taken, about 100 cubic inches of air can be drawn in, besides the tidal air. This is called **complemental air.** On the other hand, the deepest possible expiration expels 100 cubic inches of **supplemental air** in addition to the tidal air. But even after this, 100 cubic inches of air still remain in the lungs, constituting what has been called the **residual air.** Under no circumstances can this air, which fills the smallest bronchial tubes and the air-sacs, be directly renewed. The lungs are in fact so extremely spongy, that even when removed from the body and shrunk by their own elasticity far beyond what can ever take place during life, they still contain a great deal of air, and readily float on water. The following table will help to make matters clearer:—

		Cu. in.	Air in lungs.
'Vital Capacity' = C + T + S	Complemental air (C),	100	After fullest inspir. R + S + T + C.
	Tidal air (T),	30	After ordinary inspir. R + S + T.
	Supplemental air (S),	100	After ordinary expir. R + S.
	Residual air (R),	100	After fullest expiration, R.
		330	

Differences between Inspired and Expired Air.—Since breathing goes on for the sake of obtaining oxygen and getting rid of carbon dioxide, it is to be expected that expired air should contain less oxygen and more carbon dioxide than inspired air. This is actually the case.

At this stage it is desirable to enter rather more fully than has yet been done into the chemical composition of air. Perfectly dry air consists approximately of the following gases, **mixed,** not united together, so that each retains its own properties:—

	Volumes.
Oxygen,	20·96
Nitrogen,	79·00
Carbon dioxide,	·04
	100·00

Ordinary air, however, is never perfectly dry, but contains a very variable amount of **water vapour**, to the condensation of which fog, clouds, rain, &c., are due. Oxygen and nitrogen have been already studied to some extent (pp. 49, 51), and some details regarding carbon dioxide made be added here.

Carbon Dioxide, or **Carbonic Acid Gas**, is a compound the molecule of which consists of 1 atom of carbon plus 2 atoms of oxygen, and which therefore has the formula CO_2. Limestone or chalk (**carbonate of lime**) may be regarded as a compound consisting of CO_2 and quicklime chemically united. The formula for **quicklime** is CaO, *i.e.* a molecule of this compound contains 1 atom of calcium plus 1 atom of oxygen. A molecule of chalk contains the same atoms as 1 molecule CO_2 plus 1 molecule CaO, and its formula is consequently $CaCO_3$. When chalk or limestone is burnt in a kiln it is broken down into CaO and CO_2.

On the other hand, quicklime left exposed to the air gradually becomes reconverted into carbonate of lime by uniting with its carbon dioxide. Both the processes may be represented by the following chemical equation:

$$\underset{\text{carbonate of lime}}{CaCO_3} \quad \underset{\longleftarrow}{\overset{\xrightarrow{\text{by heat}}}{=}} \quad \underset{\text{quicklime and carbon dioxide.}}{CaO + CO_2}$$

Read from left to right in the direction of the upper arrow, this expresses the breaking down or **analysis** of $CaCO_3$, while read in the other direction it expresses the building up or **synthesis** of the same compound.

Carbon dioxide can be more conveniently obtained from chalk, limestone, or marble, by the action of an acid, the apparatus employed being represented in fig. 68. Some bits of limestone are put into the flask shown on the right-hand side, and hydrochloric acid poured in by the thistle funnel. Brisk effervescence ensues, owing to the liberation of carbon dioxide, which is conducted by means of the doubly bent tube to the bottom of the jar shown on the left hand side. The gas can be collected in this way because it is relatively heavy, and so gradually displaces the air in the jar. If before generating the gas, three lighted candle ends of different lengths have been placed in the jar, they will be seen to go out one after the other, the shortest first, as the carbon dioxide gradually displaces the air. It is thus proved that this gas **does not support combustion nor itself burn.** Another experiment is important, because it serves as a useful test for the presence of carbon dioxide. A small of quantity of lime-water (prepared by shaking up some quicklime with water and then filtering) is placed in a collecting jar, and carbon dioxide is passed through the liquid, which at once becomes milky, and if allowed to stand, a white sediment is deposited. This sediment consists of carbonate of lime formed by union of the CO_2 with the lime dissolved in the water, as in the chemical equation given above read from right to left. It need only be added that CO_2 is colourless, with a *slight* pungent smell, and a faint acid taste.

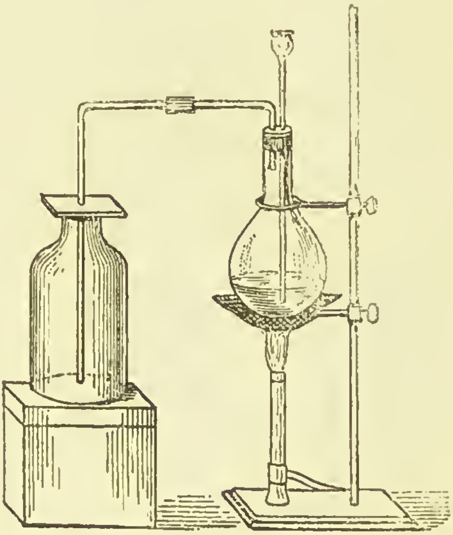


Fig. 68.—Apparatus for the Preparation and Collection of Carbonic Acid Gas from Chalk or Limestone and Hydrochloric Acid.

We are now in a position to prove that the air breathed out contains more **carbon dioxide** than the air breathed in. Two bottles, in each of which a little lime-water has been placed, are provided with tubes as shown in fig 69. A full inspiration is then taken through one bottle (B), and immediately afterwards a full expiration through the other bottle. This process is repeated two or three times. The lime-water in B remains clear, that in C soon becomes milky. In fact 4 per cent by volume of expired air consists of CO_2; *i.e.* 100 times as much as in inspired air.

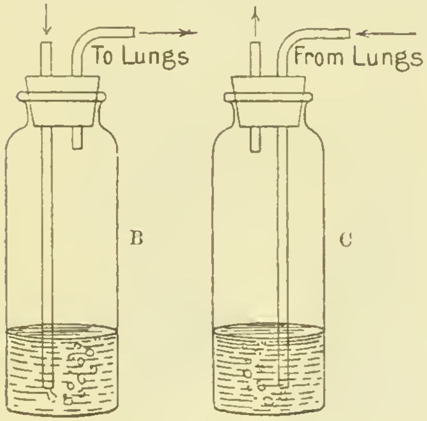


Fig. 69.—Experiment to show the difference between Inspired and Expired Air. Air is drawn into the lungs through B, and then expelled through C.

As regards **oxygen** there are about 16 volumes of it in 100 volumes of expired air, so that the air taken into the lungs loses nearly a quarter of its oxygen there. Expired air also differs from inspired air in containing a larger amount of **water vapour**, with which in fact it is saturated. The film which dims a looking-glass when breathed upon and the cloud formed by the breath on a cold day are caused by the condensation of this moisture. The air breathed out also contains a small amount of **volatile organic matter**, which easily putrefies, and is the cause of the 'stuffy' smell so noticeable in badly-ventilated rooms. **Ventilation** is necessary because it keeps up the supply of oxygen and gets rid of the carbon dioxide and organic matter present in expired air. Both of these are injurious to health, especially the latter. When the CO_2 in the air of a room rises to ·08 per cent,[1] the air may be regarded as unwholesome chiefly because organic matter is then present to a poisonous extent.

Expired air is also much warmer than inspired air, its temperature being about 97° F., which is very nearly that of the body.

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[1] $\frac{1}{2}$ oz. of lime-water shaken up with the air of the room in a 10-oz. bottle will turn milky if this percentage is exceeded.

Daily Gains and Losses.—Reckoning the tidal air as 30 inches, about 425 cubic feet of air pass through the lungs of an average adult in every 24 hours, 1200 grains of oxygen are absorbed, while 14,400 grains of CO_2 and of water are given out. This CO_2, with the accompanying organic matter, is enough to render 27,600 cubic feet of air unfit for respiration, and this amount therefore is the daily minimum required. Calculating on this basis, a room which is constantly occupied should not only be well ventilated, but be large enough to allow at least 800 cubic feet of space to each adult.

Changes which the Blood undergoes in the Lungs.—It has already been explained that the movements of breathing only renew the air in the larger air-passages. That in the air-sacs and smaller bronchial tubes is kept pure by ordinary **gaseous diffusion.** That is to say, when two gases or mixtures of gases are in direct contact currents pass in both directions until the entire volume is of the same composition. In this way the air-sacs can get rid of their carbon dioxide and water vapour while at the same time their supply of oxygen is renewed.

To understand the exchange of gases between the blood and the air in the air-sacs an addition must be made to what was said about diffusion on p. 76. It appears that, if a liquid with *dissolved gases* is separated by a moist animal membrane from a gas or mixture of gases, diffusion will take place through the membrane in both directions. Thus, if a moist bladder, containing water with carbon dioxide dissolved in it, were placed in a vessel of oxygen—(1) carbon dioxide would diffuse *out of* the water, *through* the bladder *into* the oxygen, (2) oxygen would diffuse *through* the bladder *into* the water, which would dissolve it. A similar exchange takes place between the blood and the air in the air-sacs, which will be understood when it is remembered that the blood in the capillaries of the lungs is only separated from the air in the air-sacs by the extremely thin walls of the capillaries and by the delicate epithelium which lines the sacs. The total surface represented by the lining of all the air-sacs is about equal to 100 times the area of the skin, and the spongy structure of the lungs may be regarded as an arrangement by which the blood is brought very near to the air over a very large area with great economy of space. A similar gain of absorptive surface without sacrificing compactness has already been seen in the case of the small intestine (p. 77).

The **oxygen** which the blood dispenses to the tissues is carried by the complex substance **hæmoglobin**, to which the red corpuscles owe their colour. Hæmoglobin consists of a proteid substance, **globin**, united with a red colouring matter, **hæmatin**, in which the elements carbon, hydrogen, nitrogen, oxygen, and iron occur. The peculiarity which renders it useful as an oxygen-carrier is that part of its oxygen is held in a state of *loose* chemical combination, *i.e.* is readily parted with to the tissues. It is called **oxy-hæmoglobin** when this loosely-held oxygen is present, and is then of a bright scarlet colour, but after parting with this oxygen it becomes of a dark purple colour, and is known as **reduced hæmoglobin.** The term 'reduced' is the exact opposite to oxidized, and is applied to compounds from which the oxygen has been more or less removed. Pure blood, as found in all arteries except the pulmonary, is of a bright scarlet colour owing to the presence of oxy-hæmoglobin, while impure blood, as found in all veins except the pulmonary, is dark purple because its hæmoglobin has been reduced. Hence when a blood-vessel is cut the colour of the blood flowing out is one means of determining whether an artery or vein has been injured. In the capillaries of the general body the oxy-hæmoglobin of the pure blood, supplied by the branches of the aorta, is largely converted into reduced hæmoglobin by the action of the surrounding tissues, which have a strong affinity for oxygen, causing that part of it which is loosely held to be liberated from chemical combination, after which it passes by diffusion through the delicate capillary walls into the surrounding lymph. In the lung-capillaries, on the other hand, the reduced hæmoglobin in the impure blood brought by the pulmonary artery is once more converted into oxy-hæmoglobin, the necessary oxygen diffusing into the capillaries from the air in the air-sacs.

The **carbon dioxide** of the blood is partly dissolved in the plasma and partly chemically united with the mineral salts contained in it. In the tissues the carbon dioxide formed as a product of waste passes into the lymph, and from it into the capillaries. The impure blood reaching the lungs gets rid of carbon dioxide, which diffuses from the lung capillaries into the air-sacs. The water-vapour and organic matter in the expired air have a similar source.

It is therefore in the capillaries of the general body that pure ('arterial') blood is converted into impure ('venous'), while the converse process takes place in the capillaries of the lungs.

The conversion of impure into pure blood, so far as amount of oxygen is concerned, can easily be effected **outside** the body altogether, by simply exposing it to the air. Its purple colour soon gives place to bright scarlet as the reduced hæmoglobin takes up oxygen from the air and becomes oxy-hæmoglobin. The process can be hastened by shaking up with air, or still better with oxygen. It is also possible to convert pure into impure blood outside the body, by addition of a strong reducing agent, *i e.* some substance having a strong affinity for oxygen. Such a substance is found in ferrous sulphate (green vitriol), and if some of this is added to pure blood the bright scarlet colour is changed for a dull purple. Oxygen has been withdrawn from the oxy-hæmoglobin, converting it into reduced hæmoglobin.

Suffocation or **Asphyxia** (Gk. for stopping of pulse) takes place if the same air is breathed over and over again, if some gas (other than oxygen) or mixture of gases (not containing oxygen) is substituted for air, or if breathing is stopped altogether by closure of the trachea. In such cases there is oxygen starvation, with poisoning by the waste products of respiration, and it may be in the second case by the substituted gas inhaled. It will be sufficient to consider the case where the same air is repeatedly breathed. As it becomes impure the breathing becomes more rapid, fuller, and more laboured. Then follows a stage marked by difficulty of breathing, **dyspnœa** (Gk. *dus*, bad; *pnĕō*, I breathe), where the muscles concerned in expiration contract violently, and convulsions finally set in. The last stage is one of complete exhaustion, with occasional attempts at breathing which become feebler and feebler till at last death ensues. Upon dissection all the blood is found to be dark, for its hæmoglobin is entirely reduced. The great veins, the right side of the heart, and the pulmonary artery are gorged with blood, while the left side of the heart is nearly empty.

Coughing is generally the result of irritation of the larynx or trachea. It consists of a deep inspiration with closure of the glottis, followed by a rapid and more or less violent expiration through the mouth. Irritating substances are got rid of in this way.

Sneezing resembles coughing, but in this case the eyes or nasal cavities are irritated, and expiration takes place through the nose.

CHAPTER VII.

URINARY ORGANS AND THE EXCRETION OF NITROGENOUS WASTE.

The constant waste which goes on in the body for the purpose of producing the energy and heat necessary to life leads to the production of three chief waste products: water, carbon dioxide, and urea. The respiratory organs, as explained in the last chapter, get rid of nearly all the carbon dioxide and a great deal of the water, while at the same time they are the means by which the necessary process of waste is rendered possible, since they introduce oxygen into the body. The **urinary organs**, including under this name the kidneys and related parts, have the function of excreting **water** together with **urea**, which is a nitrogenous waste product brought to the kidneys in the blood.

The clear amber-coloured liquid, **urine**, excreted by the kidneys, consists, therefore, of water with various substances dissolved in it, of which the most important is urea. Its composition given in greater detail is as follows:—

		In 1000 parts.
Water,		958
Dissolved solids consisting of,—		
Urea,	23·3	
Other nitrogenous substances,	·9	
Sodium chloride (common salt),	11·0	
Other salts, &c.,	6·8	
		42
		1000

Urine is slightly acid, and when allowed to decompose gives off a peculiar pungent odour due to the formation of ammonia. From 50 to 60 fluid ounces are excreted by the kidneys during every 24 hours, containing about 512 grains of urea.

Urea, when obtained in the solid form, crystallizes in four-sided prisms or in delicate white needles. Its chemical formula is N_2H_4CO, and it therefore contains the elements nitrogen, hydrogen, carbon, and oxygen, the first making up nearly half its weight. In decomposing urine it is converted into **ammonium carbonate** ($N_2H_8CO_3$), the substance familiarly known as 'smelling salts', by union of 2 molecules of water with 1 molecule of urea: $N_2H_4CO + H_2O + H_2O = N_2H_8CO_3$. Each molecule of ammonium carbonate then readily breaks down into 2 molecules of ammonia (NH_3), 1 molecule of water (H_2O), and 1 molecule of carbon dioxide (CO_2).

Urea may thus be regarded as the end product resulting within the body from the breaking down of its proteid constituents, and it then undergoes further changes, outside the body, leading to the production of a still simpler nitrogenous body, ammonia. It may be added that when the body dies and its soft parts decompose, the ultimate products are water, carbon dioxide, and ammonia. It is therefore desirable to learn something more about this last compound.

Ammonia is a gaseous compound the molecule of which contains 1 atom of nitrogen united with 3 atoms of hydrogen, and it therefore has the formula NH_3, as already mentioned. Water dissolves ammonia very readily, and chemists sell it in this form, for which the popular name is 'spirits of hartshorn'. The extremely penetrating odour of this solution is familiar to most people, and the similar odour given off by common smelling salts is also due to the liberation of this gas. Ammonia is usually prepared on a small scale in the laboratory by means of the apparatus represented in fig. 70. A mixture consisting of 1 part of sal-ammoniac (NH_4Cl) to 2 parts of slaked lime (CaH_2O_2) is placed in the flask on the right and gentle heat applied. Ammonia is then given off, and, being about twice as light as air, can be

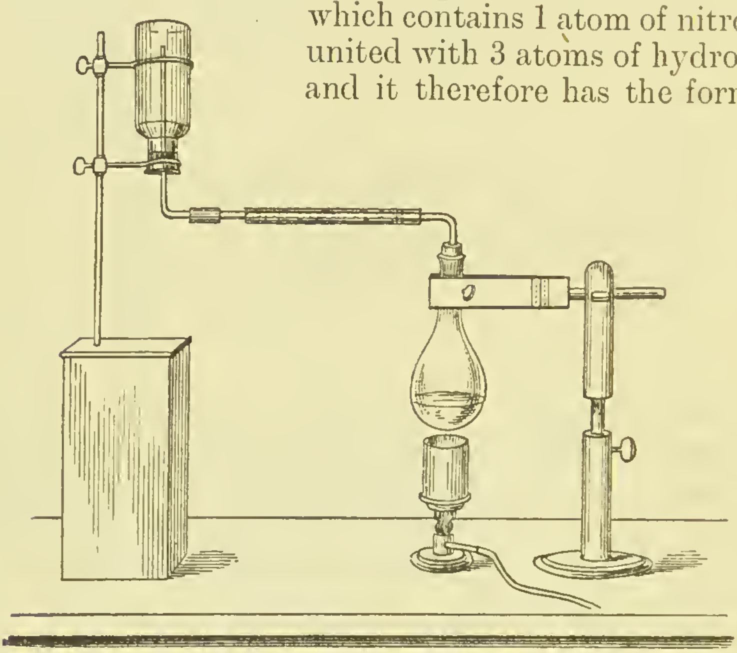


Fig. 70.—Apparatus for preparing and collecting Ammonia Gas from sal-ammoniac and slaked lime. The collecting bottle is empty and inverted to receive the gas from the delivery-tube.

passed through a bent tube and collected in a jar turned upside down, as shown on the left. The gas thus obtained will be found to be transparent and to possess a peculiar pungent odour. It will put out a lighted candle-end raised into it by means of a wire, and will not itself take fire. If the end of the tube leading from the flask is allowed to dip into a vessel of water, a solution of ammonia will be prepared. Both as a gas and in solution ammonia is strongly alkaline, *i.e.* it will turn red litmus paper blue or neutralize acids.

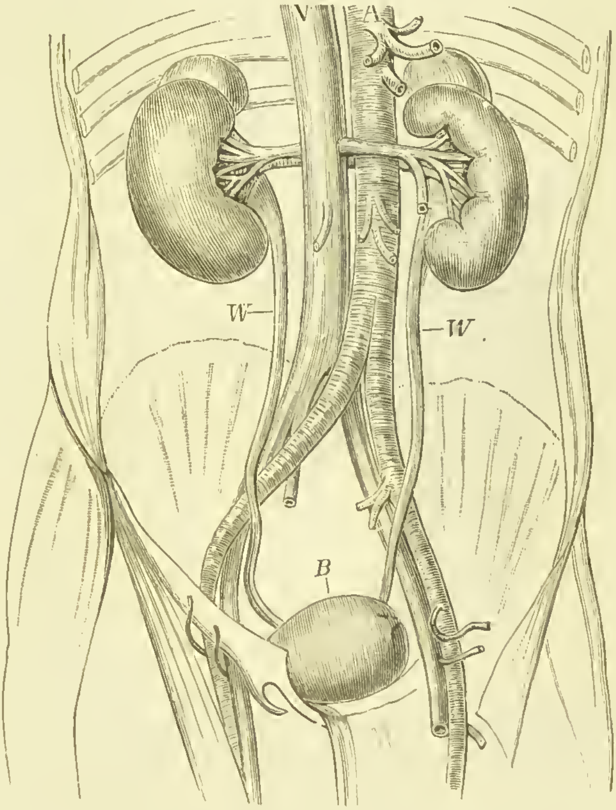


Fig. 71. — Showing the Kidneys and the Structures in connection with them.

W, W, Ureters; B, urinary bladder. In the centre of the figure (to right) is seen the dorsal aorta (A), giving off the renal arteries and forking below into iliac arteries. The inferior vena cava (V) is also seen, made up by union of the iliac veins below and receiving renal veins from kidneys.

The **Kidneys** (fig. 71) are two dark red bodies of characteristic shape, situated at the back of the abdominal cavity, one on each side of the backbone. Their upper ends are on about the same level as the last thoracic vertebra, and they are *behind* the peritoneum, which therefore only covers their front surfaces. Each kidney is about 4 inches long, 2½ inches broad, and 1¼ inches thick, with a weight of 4½ ounces or rather less. On its inner side there is a notch, the **hilus**, from which a firm-walled tube runs down to open into the back of the urinary bladder. This tube is the duct which carries off the urine from the kidney, and it is known as the **ureter**. The **urinary bladder**, which acts as a temporary receptacle for the urine, is a rounded sac with firm translucent walls, containing layers of involuntary muscle. The bladder, when moderately full, contains about a pint of liquid. It communicates with the exterior at its lower end by a tube, the **urethra**, the beginning of which is kept closed by a sphincter muscle (p. 65).

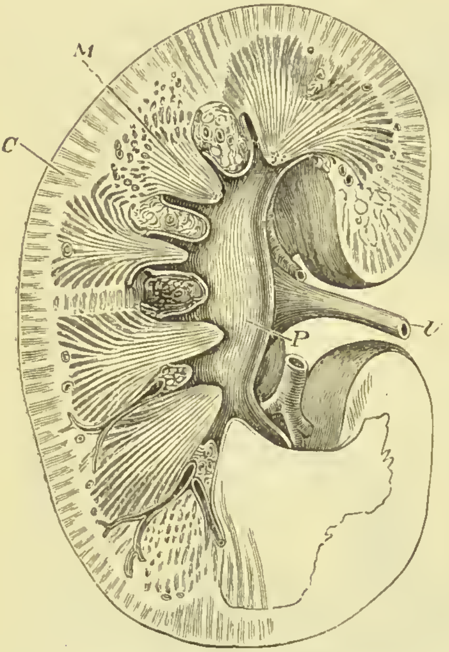


Fig. 72.—Showing a Kidney cut through in the direction of its length. Above the ureter (U) is seen the cut end of a branch of the renal vein —below it, the cut end of a branch of the renal artery. P, pelois; C, cortex; M, medulla.

Structure of the Kidney.—The kidney is covered by a firm fibrous coat which can readily be peeled off. When cut through longitudinally from side to side the cut surface presents the appearance represented in fig. 72. The outer part or **cortex** (L. for bark) is soft, dark red in colour, and granular-looking, while the inner part or **medulla** (L. for marrow) is firmer, paler, and marked by fine streaks diverging towards the cortex. The medulla is divided into a number of conical masses or 'pyramids', of which 12 or more are generally present. The broad ends of the pyramids are continuous with the cortex, while their narrow ends constitute a number of rounded elevations, the **urinary papillæ**, which project into a cavity (**pelvis**) formed on the inner side of the kidney by expansion of the ureter at the hilus.

If the surface of a urinary papilla is examined with a lens, a number of minute apertures can be seen, which are rendered more obvious by squeezing, when minute drops of urine ooze from them. The kidney is in fact made up of an enormous number of microscopic **uriniferous tubules** by which the urine is excreted. Each of these tubules begins in the cortex with a small round **Malpighian body** visible as a red spot by means of a lens. It then twists about in a very complex way and finally runs straight through the medulla, uniting as it does so with other similar tubules till a rather wider tube is formed which opens on a urinary papilla by means of one of the minute apertures already mentioned. The striated appearance of the medulla is due to the straight course which the tubules take as they converge to the urinary papillæ. The tubules are lined throughout by a layer of simple epithelium, the character of which varies in different places. The only regions which need be considered further here are the Malpighian body and the thickened part of the tubule running in the cortex. A **Malpighian body** (fig. 73) is a rounded structure lined by flattened epithelium and having a tuft of capillaries, the **glomerulus** (L. for small skein of thread), pushed into it, so to speak. The glomerulus is not, however, *inside* the cavity of the capsule, but has much the same relation to it that the heart has to the pericardium (p. 85). The thickened part of the tubule is lined by glandular

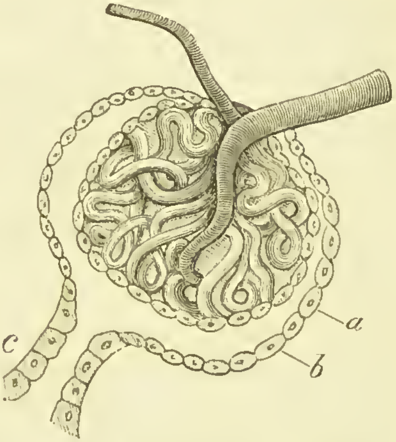


Fig. 73.—Malpighian Body of Kidney, with its tuft of vessels.

a and *b*, Cells of capsule formed by dilated end of tubule *c*. The wide vessel is the afferent; the narrow one is the efferent. Very largely magnified.

epithelium, a small part of which is shown in fig. 74. Since the uriniferous tubules excrete the urine from the blood, it is desirable to have some notion of the arrangement of the blood-vessels of the kidney. A **renal artery** (fig. 71) runs from the aorta to the hilus, and divides up into smaller and smaller branches. Some of these run in the cortex and give off twigs to the glomeruli (*wide* vessel in fig. 73). The blood is carried off from each glomerulus by a minute vein (*narrow* vessel in fig. 73), which at once breaks up in the same way as a portal vein and becomes continuous with a network of capillaries, by which the thickened parts of the tubules are closely surrounded. From this network, and from capillaries in the medulla, small veins arise which by successive union finally produce the **renal vein**, which runs from the hilus into the inferior vena cava (fig. 71). The blood in this vein is the purest in the body, as far as nitrogenous waste is concerned.

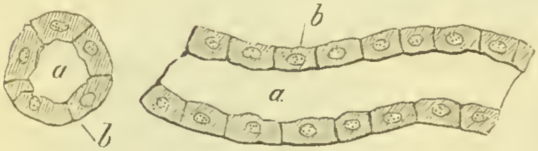


Fig. 74.—Very highly magnified view of Cross and Longitudinal Section of a Tubule. *b*, Cells; *a*, channel of a tubule.

The **water** and **inorganic salts** of the urine appear to be filtered out of the blood in the glomeruli into the beginnings of the uriniferous tubules. It must be remembered, however, that we have to deal in this case with a *living* filter that has the power of *regulating* what shall pass through it and what shall not. If it were not for this *all* the dissolved substances in the blood would be able to filter through into the tubules, which is very far from being the case. The glandular epithelium lining the thickened part of the tubules appears to have the function of separating **urea** and certain other nitrogenous substances from the blood in the surrounding capillary network. From the epithelium they pass into the cavities of the tubules, which are constantly being washed out by the fluid filtered through the glomeruli.

CHAPTER VIII.

THE SKIN AND ITS FUNCTIONS—METABOLISM AND ANIMAL HEAT.

The skin has already been mentioned on p. 14 as an important **protective** organ, and its division into epidermis and dermis was there explained. Other important functions are performed by the skin besides the one just mentioned. It is an **excretory organ**—the excretion being called perspiration or sweat,—it helps to **regulate the temperature** of the body, and it is the **organ of touch.**

The **structure** of a magnified section of skin, taken at right angles to the surface, is represented in fig. 75. The **epidermis** (*ab*) is comparatively thin, but varies in thickness in different parts of the body. It is thickest (about $\frac{1}{24}$ of an inch) on parts exposed to pressure, such as the palms of the hands and soles of the feet: in some places it is not more than $\frac{1}{240}$ of an inch thick. The under surface of the epidermis is irregular and moulded upon the correspondingly shaped upper surface of the dermis (*c*). Epidermis is a form of stratified epithelium, and is made up of numerous layers of cells which are more or less rounded near the dermis, but externally are scale-like and constitute what is called the horny layer (*a*). The deeper part of the epidermis contains pigment, and is termed the Malpighian layer (*b*). **Hairs** belong to the epidermis, and may be looked upon as compressed piles of dead cells in the form of horny scales. Each hair grows out of a narrow pouch, the **hair-sac** (see fig. 75) which is lined by epidermis but projects down into the dermis. The hair grows by addition of material to its base. Two or more little pouches, the **sebaceous glands** (*f*), open into the hair-sac. They are lined by glandular epithelium and secrete a greasy substance which acts as a natural pomatum. The nails of the fingers and toes are of much the same nature as hairs, and are developed in a similar way. They are as it were enormously large flat hairs. The sebaceous glands are not the most important ones belonging to the skin. If the tip of a finger or thumb is carefully examined a number of delicate ridges will be seen arranged in a peculiar manner. It is owing to these ridges that the print of a dirty finger or thumb has a well-known and characteristic appearance. If by means of a fairly strong lens, one of these ridges is carefully examined, a row of minute holes will be seen running along it. These are the openings of the **sweat-glands**, by which the sweat is excreted. Each of these glands is an exceedingly delicate tubule about $\frac{1}{4}$ of an inch long, the beginning of which is coiled up into a kind of ball (*e*) in the deeper part of the dermis, or in the **subcutaneous** (L. *sub*, below; *cutis*, skin) **tissue** (*c′d*) which lies below it. This coiled part is lined by glandular epithelium. The rest of the tubule, which may be called its duct, runs with a wavy course (*e′*) through the dermis, and then, twisting like a corkscrew, pierces the epidermis to end by one of the pores already mentioned. The epithelium lining the gland belongs to the epidermis. Sweat-glands are found in almost all parts of the skin, but are not equally numerous in every region. They are most abundant in the palms of the hands and soles of the feet, where about 3000 are found to the square inch. Where least abundant, as in the skin of the back, about 400 of them occur to the square inch. There must be between two and three million of them altogether, and if unravelled and placed end to end in a straight line they would stretch a distance of not less than ten miles.

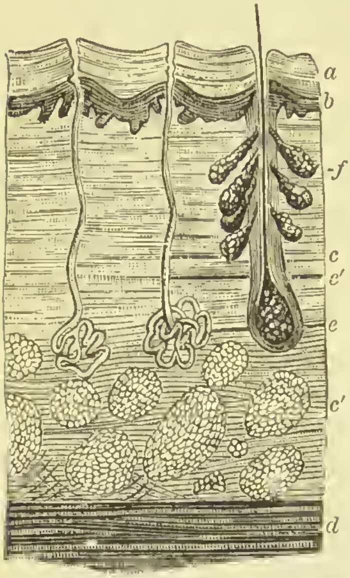


Fig. 75.—The Structure of the Skin. Magnified.

The **dermis** (fig. 75 from just below *b* to *c*) is much thicker than the epidermis and passes without sharp boundary internally into the subcutaneous tissue ($c'd$), which is of similar texture, but distinguished by containing a good deal of fat (*oval areas in the figure*). The outer surface of the dermis is irregular, and in the sensitive parts of the skin raised into numerous minute papillæ. It is the arrangement of these in a regular manner that gives rise to the ridges on the fingers mentioned above. The dermis consists of a felt-work of connective tissue, traversed by numerous blood-vessels, lymphatics, and nerves. It therefore bleeds when injured, and is sensitive.

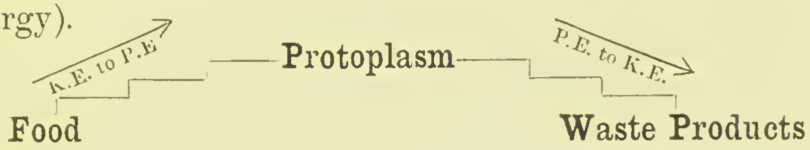
Excretion by the Skin.—**Sweat** is an acid liquid, the composition of which resembles that of very much diluted urine. 1000 parts by volume consist of 988 parts of water with 12 parts of dissolved solids. Of these last nearly 3 consist of sodium chloride, less than 1 of urea, and the rest of small quantities of various salts and organic compounds. Under ordinary circumstances the sweat evaporates into the surrounding air as soon as it reaches the surface of the skin, and in this form is known as 'insensible perspiration', but when violent exercise is taken, or the body is exposed to a high temperature, drops of sweat collect on the skin, constituting 'sensible perspiration'. In fact, under such circumstances, the sweat is secreted more rapidly than it can be got rid of by evaporation. About 2 pounds of sweat are excreted every 24 hours.

Regulation of Body Temperature by means of the Skin.—Under all circumstances, the healthy human body maintains a constant temperature of about 98·6° F. as measured by means of a thermometer placed in the arm-pit. The temperature of the blood is about 100·6° F. But the heat produced in the body constantly varies in amount, being more, for example, when a great deal of exercise is taken, and less when but few movements are made. A regulating apparatus is therefore required, and this is constituted by the skin, working under the control of the nervous system. Heat is being continually given off from the surface of the skin by radiation, and also as a result of the evaporation of sweat. The latter point will be realized by remembering how cold the skin feels if damped with warm water, and then allowed to dry by letting this evaporate. A similar effect is brought about by means of the perspiration. When too much heat is produced in the body the skin becomes red and hot, while at the same time the production of sweat is largely increased. Two things have happened leading to this result—(1) the **vaso-motor nerves**, which regulate the size of the arteries supplying the skin, have caused these to increase in size (p. 100) and to bring more blood, (2) special **secretory nerves** have stimulated the sweat-glands to produce more sweat. An attempt is being made, in fact, to get rid of as much heat as possible from the surface of the skin. It is now moist and unusually full of blood, conditions which favour the escape of heat through it. It is also clear that the increased secretion of sweat leads to a greater loss of heat by means of evaporation. Exactly the opposite kind of thing takes place if the loss of heat has to be *reduced*, as, for example, in cold weather if little exercise is taken. The skin may then be pale and cold, and the sweat reduced in amount. The arteries supplying the skin are contracted by the influence of the vaso-motor nerves, and the sweat glands are not stimulated to extra secretion. The primary use of clothes in this climate is to assist the skin in preventing loss of heat.

METABOLISM.

The actual *living substance* of the body, **protoplasm** (Gk. *prōtŏs*, first; *plasma*, something formed), is of exceedingly complex chemical nature and very unstable, *i.e.* very liable to break down into simpler substances. It is known to consist very largely of proteids, and probably of carbohydrates and fats as well. The body also contains a large number of *lifeless substances*, some of which are on their way to become protoplasm while some have resulted from its breaking down in various ways. The term

Metabolism (Gk. *mĕtabolē*, change) is conveniently applied to the entire cycle of changes by which the digested food is converted into protoplasm on the one hand, and by which waste products are ultimately produced on the other by breaking down of protoplasm. The up-building processes may be grouped under the heading **Constructive Metabolism**, and the down-breaking processes under the heading **Destructive Metabolism**. The former involves the absorption of heat and the conversion of actual or **kinetic energy** into stored or **potential energy**. The latter is associated with the conversion of potential into kinetic energy, which appears as heat and mechanical work. These facts can be represented diagrammatically as follows.—(K.E. = Kinetic energy; P.E. = potential energy).



The diagram is made like a staircase to indicate that there are a number of upward steps between food and protoplasm and a number of downward steps between protoplasm and waste products. But this is not all, for it appears that a considerable part of the food is not built up into protoplasm at all, but is slowly oxidized into waste products, with conversion of potential energy into heat and mechanical work. We may compare the living body to an imaginary steam-engine (cp. p. 47) which does work and keeps up its heat partly by the combustion of fuel and partly by the combustion of its own walls. We must further suppose this steam-engine to possess the power of repairing its walls from part of the fuel as rapidly as they are burnt away, and thus, though the shape of the engine would be maintained, the materials making it up would be constantly altering. Another way of expressing the fact that living matter is constantly being broken down is to say that all parts of the body continually undergo '**local death**', but it must not be forgotten that this is compensated by constant renewal. Death in the ordinary sense or '**general death**' in the physiological sense means the stoppage of the various functions that distinguish the body as a whole, but not the immediate death of all the tissues. In the dead body destructive metabolism continues to go on without any counterbalancing constructive metabolism.

Animal Heat.—As stated above, one of the results of metabolism is the production of heat, and it must now be emphasized that the down-breaking processes which liberate it are of the nature of slow combustion or oxidation. Hence the necessity for taking in free oxygen, which, so to speak, seizes on the carbon and hydrogen in the compounds found within the body, and unites with them to form carbon dioxide and water. In the oxidation of the nitrogenous compounds the ultimate product, so far as concerns nitrogen, is urea.

Most of the heat of the body is produced by the metabolism of the muscles, and a considerable amount in the glands, but more or less of it is liberated in all parts of the body. The **circulatory organs** among their many functions include that of **heat distribution**, just as air and water currents distribute heat and so tend to equalize the temperature of the earth. Heat is lost from the surface of the skin, and with the fæces, urine, and expired air. The regulation of heat by means of the skin has already been sufficiently explained.

Work done by the Body.—The actual energy set free, by the processes of oxidation already described, is largely manifested in the external work done by the body in locomotion, &c., and in the internal work performed by the various organs. The average day's external work performed by an industrious workman has been estimated at 483 foot-tons, work equal to that expended in raising 483 tons one foot or 1 ton 483 feet.

CHAPTER IX.

THE NERVOUS SYSTEM AND ITS FUNCTIONS.

The **Nervous System** includes those structures by means of which all the organs of the body (p. 16) are correlated, and caused to work in harmony with one another and the surroundings. This is necessary, because, in accordance with the principle of division of physiological labour (p. 13), different parts are specialized for performing the functions of digestion, respiration, circulation, &c., and if they worked independently of one another the most disastrous results would at once follow. The nervous system, in fact, undertakes the direction and control of the whole body, and all the higher manifestations of life are dependent upon it. Take such an apparently simple matter as the maintenance of the erect position (p. 46). This depends upon the constant transmission of what may figuratively be called 'orders', from the nervous system to the muscles concerned. When a person goes into a dead faint some of the actions of the nervous system are temporarily suspended, including the sending out of these orders, and, as a result, the erect position is no longer maintained. More serious interference with the nervous system may lead to stoppage of the heart or of the respiratory movements, and in that case death ensues unless the interference is of extremely brief duration.

The organs now being dealt with, consist of (1) the **Central Nervous System**, including the brain, spinal cord, and sympathetic ganglia—and (2) the **Peripheral Nervous System**, including the nerves by which these parts are brought in relation to the other organs of the body. It will not be convenient, however, to completely separate the consideration of the two.

The **Cerebro-spinal Axis**, under which name Brain and Spinal Cord are included, is contained in the dorsal cavity or **neural canal** (fig. 1), bounded by the vertebrae and bones of the skull. It is surrounded by three membranes, all mainly composed of connective tissue. The most external of these, the **dura mater** (L. for hard mother) lines the neural cavity and is very firm and tough. Within it is a very narrow **sudural space** filled with lymph, and resembling in its characters the space between the two layers of the pericardium or the two layers of a pleura. Now follows an extremely delicate **arachnoid membrane**, which received its name (Gk. *arachnēs*, spider's web; *eidŏs*, resemblance) from the numerous delicate strands of connective tissue which run across the large **sub-arachnoid space** situated below it. This space is filled with clear **cerebro-spinal fluid**, which is like lymph in apperance, but contains no corpuscles and differs in composition. The third membrane is the **pia mater** (L. for tender mother), which is fairly delicate and closely invests both brain and spinal cord, supporting numerous blood-vessels taking blood to and from them.

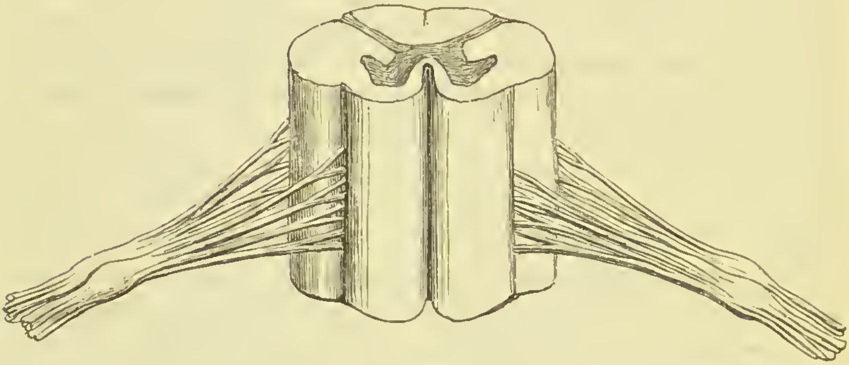


Fig. 76.—Section of Spinal Cord, with Roots of Spinal Nerves. Front View.

The **Spinal Cord** or **Spinal Marrow** is a cylindrical mass of nervous matter about 18 inches long. It is continous above with the brain, at the foramen magnum, and tapers below into a filament, the **filum terminale** (L. for end thread). When examined more closely a deep longitudinal groove or fissure is observed running along the front, and a similar one along the back of the cord (fig. 76).

In a cross section (fig. 77) it is seen that these two fissures (I and II) are deep clefts by which the cord is divided into right and left halves, connected by a narrow central bridge, which is traversed by a narrow central canal (*cc*). Each half is marked externally by two longitudinal grooves dividing it into **anterior** (AC), **lateral** (LC to LC), and **posterior** (PC) '**columns**' (fig. 76). Further inspection of a cross section will show that the cord is not made of the same kind of material throughout. There is an outer part consisting of a white substance and an internal core of rather darker colour. These two kinds of material are respectively known as '**white**' and '**grey**' **matter**, and without going into detail it may be stated that the former is made up of exceedingly delicate **nerve fibres**, the largest of which are not more than $\frac{1}{1280}$ of an inch in breadth (= $2\frac{1}{2}$ the breadth of a red corpuscle), while the latter largely consists of **nerve cells**, the very largest of which are about $\frac{1}{260}$ of an inch broad, and just visible to the naked eye. Most nerve cells, however, are smaller than this: a breadth of $\frac{3}{1000}$ of an inch may be taken as the average. The grey matter of the spinal cord, as seen in cross section, presents an outline which has been compared to a butterfly, or to two crescents placed back to back and united by a transverse band (fig. 77). The two ends of each crescent may be conveniently spoken of as the **anterior cornu** and **posterior cornu** (L. *cornu*,

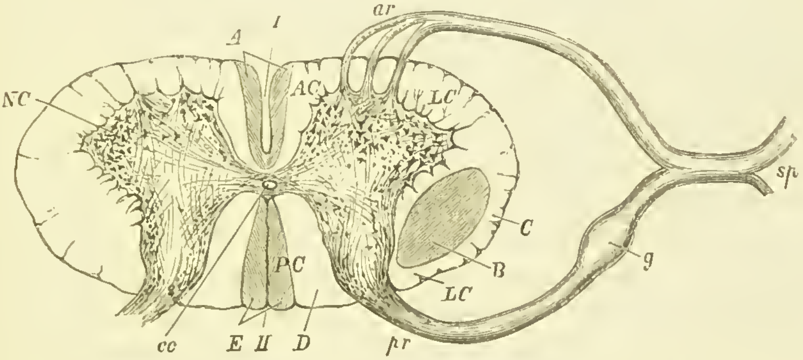


Fig. 77.—Cross Section of the Spinal Cord, front side above. Partly diagrammatic. Magnified. For references see text.

horn) respectively. The spinal cord gives origin to a large number of **spinal nerves**, which supply the neck, trunk, limbs, and part of the head. Each such nerve is made up by the union of two 'roots' or bundles of nerve fibres, as shown in figs. 76 and 77, one placed in front and the other at the back. The **anterior root** (*ar*) arises opposite the anterior cornu of the grey matter, at the junction of the anterior and lateral columns, while the **posterior root** (*pr*) takes origin opposite the posterior cornu, at the junction of the lateral and posterior columns. Upon this root there is a small swelling or **spinal ganglion** (*g*) (Gk. for small tumour), in which, as in all similarly-named masses, nerve cells are found. The two roots unite together in an intervertebral foramen (p. 28) to form the **trunk** (*sp*) of a spinal nerve, which almost at once begins to give off branches. There are thirty-one pairs of spinal nerves in all, named from the vertebral regions to which they belong. The roots of the lower spinal nerves have to run downwards in the spinal canal for some time before they get to their intervertebral foramina, and, together with the filum terminale, look something like a horse's tail, on which account the collective name of **cauda equina** (L. for horse's tail) has been given to these structures. The **nerve fibres** which make up a spinal nerve begin in the grey matter, as is shown in fig. 77. They are then bound up by connective tissue into the roots, and these are united in the same way into the spinal nerve. Some of the upper spinal nerves unite on each side into a network or **plexus** (L. for woven), from which the nerves for the corresponding upper limb are given off, and a similar plexus supplying the lower limb is formed on each side by union of some of the lower nerves. A **phrenic nerve** (Gk. *phrēn*, midriff) runs back on each side from the spinal nerves of the neck to the diaphragm. If a spinal nerve is traced to its distribution its branches will be found to have two chief destinations, (1) to the muscles, (2) to the skin, which thus are connected with the spinal cord, and by its means with the brain. It must be noted that the grey matter of these organs is the part which gives them a right to be called 'central', is, in short, the tissue by which the direction and management of the body are carried on. The grey matter may be figuratively compared to a complicated collection of telegraphic offices, some of greater and some of less importance, the headquarters being in the brain. Various ganglia lying outside the neural canal altogether may be looked upon as outlying offices. But just as telegraphic offices are placed in communication by means of wires so are the various masses of grey matter connected with one another, and with other parts of the body, by means of nerve-fibres. The simile must not be pressed too far, and it must not be forgotten that the nerve-fibres are alive. When an electric current passes along a wire the minute molecules which make up the wire successively undergo some kind of vibration, a kind of limited movement which brings them back to the same spot again, just as is the case with a pendulum. When what is called a 'nerve impulse' passes along a nerve fibre something of a similar kind happens, but its exact nature is not known. Most of the nerve-fibres which can be traced into muscle may be called **efferent fibres** (L. *ex*, from; *fero*, I carry), because they carry nerve impulses *from* the grey matter; and since these impulses cause the muscle to contract, and therefore to move, these fibres may further be termed **motor.** It is found that, if the motor nerve supplying a muscle be cut, that muscle no longer contracts under ordinary circumstances. In other words the muscles of the body only do their work under the direction of the central nervous system. This is exemplified in certain injuries to the hand, whereby the nerves supplying some of the finger muscles are cut through, with the result that the power of working those muscles is lost. In the case of most of the fibres traceable into the skin, impulses are carried *to* the central organs, and such fibres are therefore termed **afferent** (L. *ad*, to; *fero*, I carry). Their duty is to convey information, so to speak, to the grey matter, and since the result is often a sensation, it may be of contact or of heat, many of them get the name of **sensory** fibres. Notice here, however, that *all* afferent fibres are not sensory, nor are *all* efferent fibres motor.

Functions of the Roots of the Spinal Nerves.—The peculiar double way in which the spinal nerves arise naturally suggests that the two roots are of different physiological nature, and the following experiments prove that this is actually the case. It must be borne in mind that a **stimulus** (L. *stimulus*, goad) is any agency by which nerve impulses are started or modified, and a nerve is said to be **stimulated** when such an agency is brought to bear upon it.—(1) When *both* roots of a spinal nerve are cut, feeling and the power of movement are both lost in the part supplied. From this the conclusion is drawn that feeling and power of movement are alike dependent upon nerve-supply. (2) When the *anterior* root only is cut the power of movement is lost while feeling remains. When, on the other hand, the *posterior* root is cut, feeling is lost but the power of movement remains. The conclusion is therefore drawn that the **anterior root** consists of **motor fibres** and the posterior root of **sensory fibres**, the two roots uniting together to form a **mixed** nerve, *i.e.* one in which fibres of both kinds are present. (3) The foregoing conclusions can be *verified* by stimulating the cut ends of the roots and observing the effects. Such stimulation may be mechanical, *e.g.* by pinching with a pair of forceps, thermal by application of heat or cold, chemical as by application of acid, or electrical by means of a galvanic current. If the *proximal* end (*i.e.* the one connected with the spinal cord) of an *anterior* root is stimulated *no* obvious result follows, but if the *distal* end (*i.e.* the one connected with the nerve trunk) is stimulated *contractions of the muscles* at once take place. If, on the contrary, the *proximal* end of a *posterior* root be cut, there will be *manifestations of pain*, while *no* obvious result follows stimulation of the *distal* end. It is clear that, when no obvious effect results from stimulation, an attempt is made to send impulses the *wrong way*, while when an obvious result is obtained it must be supposed that nerve impulses are being set up in the same direction as under normal conditions. In other words, the fibres of the **anterior root** carry impulses **outwards** towards the muscles, while those of the **posterior root** carry impulses **inwards** towards the spinal cord. Thus the former conclusion is borne out, that these roots are respectively made up of motor and sensory fibres.

Muscle-nerve Preparation.—The action of motor nerves on muscles can be very conveniently studied in what is known as a muscle-nerve preparation from the body of the frog. In this and other cold-blooded animals the tissues remain alive for a long time after the animal has been killed (p. 126), even when removed from the body altogether. A frog, rendered insensible by ether, is killed by destruction of the brain or by decapitation. One of the hind legs is skinned, and the muscles of the back of the thigh separated from one another. A large **sciatic nerve** will then be seen running close to the femur. This nerve is traced down into the large **calf-muscle** (gastrocnemius), to which it gives branches. The muscle in question is dissected out with the lower end of the femur to which it is attached above, and with a piece of the sciatic nerve. A muscle-nerve preparation (fig. 78) is thus obtained in which stimulation of the nerve by appropriate means causes the muscle to contract. In applying stimuli to the nerve we are, so to speak, playing the part of the central nervous system, and sending nerve impulses along it to the muscle.

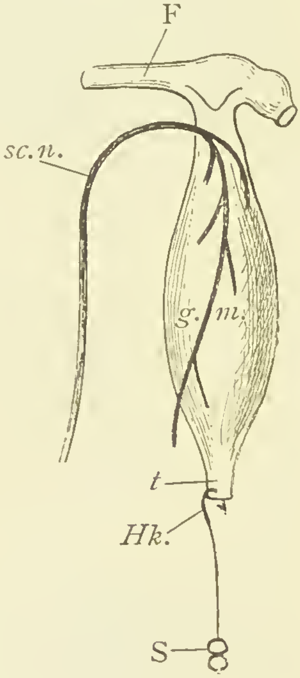


Fig. 78.—Muscle-nerve Preparation (enlarged).

F, Stump of femur; *sc. n.*, sciatic nerve, sending branches to the gastrocnemius muscle *g.m.*; *t*, lower tendon of muscle; *Hk*, hook; *S*, shot.

Functions of the Spinal Cord.—The spinal cord serves as a means of communication between the brain and those parts of the body which are supplied by the spinal nerves. In virtue of its grey matter it is also able to do independent work in bringing about what are known as reflex actions, the nature of which will be explained in a subsequent paragraph.

That the cord **conducts nerve impulses** to and from the brain is proved by cases where it has been divided or badly crushed (as when the back is 'broken' by an accident) so that the part of it below the injury is cut off from the brain. In such cases feeling and power of movement are lost in those parts which receive their nerve-supply from the piece of cord so disconnected.

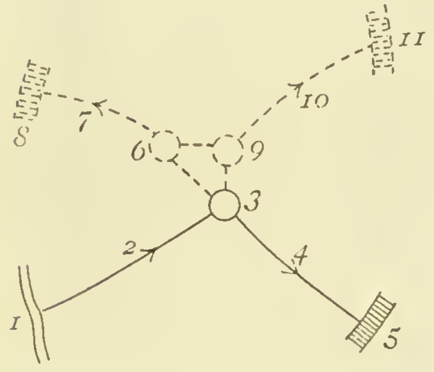


Fig 79.—Diagram of Reflex Action.

A simple case represented by non-dotted part —1, sensory surface; 2, afferent nerve; 3, nerve-centre; 4, efferent nerve; 5, muscle. The entire diagram represents a more complex case, where other centres, 6 and 9, efferent nerves, 7 and 10, and muscles, 8 and 11, are brought into action. The arrows indicate the direction of nerve impulses.

Reflex actions are those which result from the application of a stimulus and are independent of the will. The nervous apparatus necessary for the performance of such an action consists of 3 parts: (1) an **afferent nerve**; (2) a **nerve-centre**, *i.e.* a group of nerve-cells acting together; (3) an **efferent nerve** (fig. 79). A good example of reflex action is the drawing up of the leg which takes place when the sole of the foot is tickled in a sleeping person. In this case the sensory nerves of the tickled skin represent (1), part of the grey matter of the spinal cord constitutes (2), and the motor nerves of the muscles concerned correspond to (3). As the result of tickling nerve impulses are set up in (1), travel to (2), and are, so to speak, 'reflected' downwards along (3). Reflex actions like the one described can be effected in cases of broken back, thus proving that the spinal cord is able to do certain work without the aid of the brain. The student must, however, be cautioned against supposing that what takes places is the simple transmission of a nerve impulse, for no doubt this impulse is modified to a greater or less extent by the structures through which it passes.

The **grey matter of the spinal cord** can be mapped out into a very large number of **nerve-centres**, which have special duties. These centres are, however, all connected together, like so many telegraphic offices, and when necessary can co-operate together in various ways. Here again the frog is a very convenient animal upon which to demonstrate. After destruction of the brain the frog is hung up by the lower jaw, and in a few seconds remains quite motionless, and would do so till all the tissues died if external stimuli were not brought to bear upon it. If, now, one of the toes is pinched the leg is drawn up. A small piece of blotting-paper, soaked in dilute acid, is next placed on the skin of the back and sensory nerves thereby stimulated. Movements of the legs follow, directed to the removal of the piece of paper, and if this is not at once effected the movements become more vigorous, and spread to other parts till the whole body is convulsed. Physiologically expressed, a larger and larger number of nerve-centres work together for the same end; the muscles controlled by these centres, through motor nerves, being brought into action. (Cp. fig. 79.)

The **Brain** (fig. 80) is the most important organ in the body, and as such it is not surprising that its structure should be exceedingly complex. It consists of (1) a *central axis*, which may be considered as an enlarged continuation of the spinal cord, (2) of large *outgrowths* from this axis. These outgrowths are so large that they overlap and very largely conceal the axis.

(1) The **Axis of the Brain** is divisible into 3 parts, as follows:—(*a*) The **medulla oblongata** (L. for oblong marrow) or **spinal bulb**, the lower end of the axis, and therefore directly continuous with the spinal cord which it resembles in structure, consisting like it of white

matter externally and grey matter internally. Its upper end is, however, very much larger than the cord. Within the bulb there is a good-sized cavity, the **4th ventricle**, continuous with the very narrow central canal which runs along the centre of the cord. (*b*) The **mid brain**, a small region containing a narrow tubular cavity, the **iter** (L. *ĭter*, road) continuous with the 4th ventricle. The roof of this cavity is raised into 4 small rounded elevations, the **optic lobes**, while its floor is thickened into two longitudinal masses of white matter, known as the **crura cerebri** (L. for legs of the brain). Grey matter is present round the iter, and in the optic lobes. (*c*) The '**twixt brain**, a larger region constituting the top of the axis. It contains a vertical slit-like cavity, the **3rd ventricle**, continuous below with the iter. The side-walls of this cavity are called the **optic thalami** (L. *thalamus*, bed), and a good deal of grey matter is contained within them.

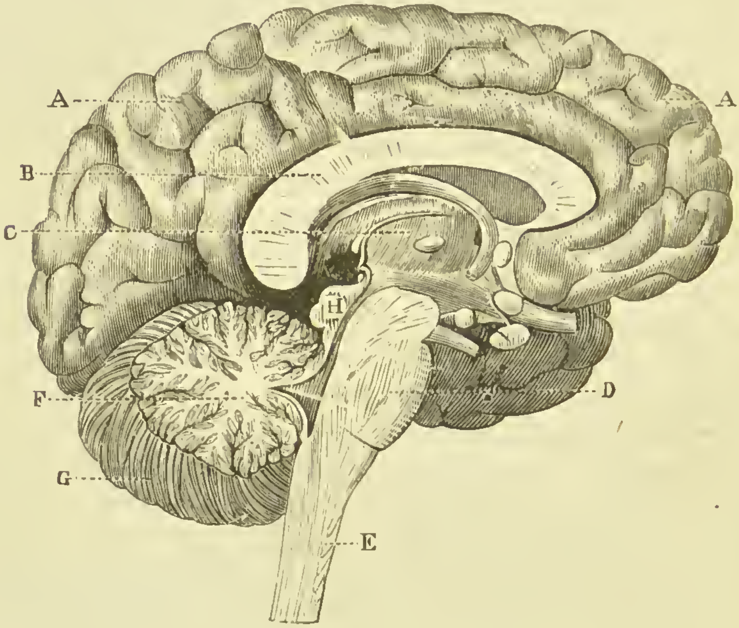


Fig. 80.—Median Longitudinal Section of the Brain.

A A, Left cerebral hemisphere; B, corpus callosum; C, 'twixt brain; D E, medulla oblongata; F G, cerebellum, the cut surface of which shows the arbor vitæ; H, optic lobes.

(2) **Outgrowths.** These are (*a*) the cerebellum, and (*b*) the cerebral hemispheres.

(*a*) The **Cerebellum** (L. for little brain) is a large outgrowth from the back of the bulb, and its surface is marked by very numerous fissures which extend for a long way into its substance. When the cerebellum is cut through it is found that most of its grey matter forms a surface layer or crust, which follows the complex fissures and gives rise to a tree-like appearance (**arbor vitæ** = L. for tree of life). This layer is the **cortex** (L. for bark) of the cerebellum, and the fissures are to be regarded as a means of increasing its extent within small bulk.

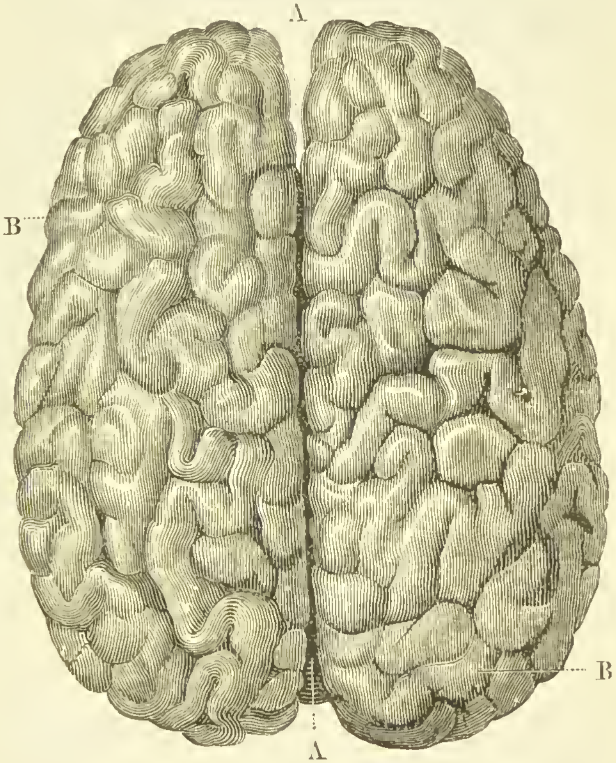


Fig. 81.—View of Upper Surface of the Brain.

A A, Great longitudinal fissure; B B, cerebral hemispheres.

(*b*) The **Cerebral Hemispheres**, together forming the **Cerebrum**, are outgrowths from the 'twixt brain. They are of very large size, and this is chiefly why the human brain differs so markedly in appearance from that of a rabbit, or still more from that of a frog. They make up the greater part of the brain, and are flattened where they abut against one another, but strongly curved elsewhere (fig. 81). The exterior of the hemispheres is marked by very numerous winding grooves, having a complicated arrangement The rounded elevations between these grooves are termed the **cerebral convolutions**, and owing to their presence the hemispheres possess a surface much greater than would otherwise be the case. Each hemisphere contains a relatively small cavity of complicated shape, known as a **lateral ventricle**, and communicating by a small hole with the 3rd ventricle. As in the case of the cerebellum, the grey matter of the hemispheres is chiefly present as a surface layer, and this **cerebral cortex** is greatly increased in extent by the presence of convolutions. Below the cortex comes a large amount of white matter, imbedded in which are some comparatively small masses of grey matter. The two hemispheres are connected together across the middle line by a broad band of white matter known as the **corpus callosum** (L. for hard body).

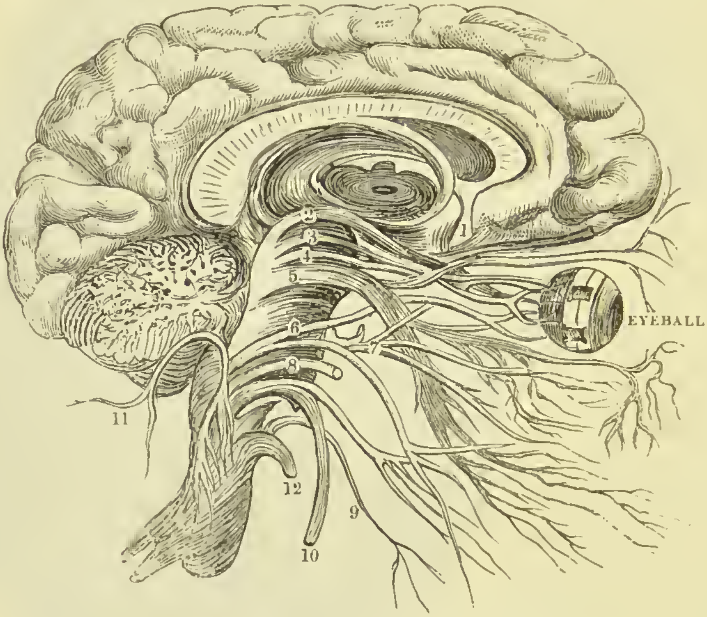


Fig. 82.—Brain and Roots of Cranial Nerves, numbered in order.

The white matter of the various parts of the brain just described consists of an immense number of nerve-fibres, serving to connect together the different tracts of grey matter, in which it has been estimated that there are some millions of nerve-cells. These are grouped into a very large number of **nerve-centres**, performing different offices.

Cranial Nerves (fig. 82). Twelve pairs of nerves are given off from the brain. They are as follows:—

Name.	Nature of fibres.	Use.	Arise from
I. **Olfactory**	sensory	nerve of smell	cerebral hem.
II. **Optic**	sensory	nerve of sight	'twixt and mid brain
III. **Oculomotor**	motor	nerve for most eyeball muscles	mid brain
IV. **Pathetic**	motor	nerve for one of the eyeball muscles	mid brain
V. **Trigeminal**	mixed	sensory n. for skin of face, part of mouth and nose, and teeth. Motor n. for jaw muscles	bulb
VI. **Abducent**	motor	nerve for one of the eyeball muscles	bulb
VII. **Facial**	motor	nerve for muscles of face	bulb
VIII. **Auditory**	sensory	nerve of hearing	bulb
IX. **Glosso-pharyngeal**	mixed	nerve of taste(?) and motor n. for muscles of pharynx	bulb
X. **Vagus**	mixed	sends branches to larynx, heart, lungs, liver, and stomach	bulb
XI. **Spinal Accessory**	motor	nerve for some of the neck muscles	bulb
XII. **Hypoglossal**	motor	nerve for muscles of tongue	bulb

It will be seen from the above that the cranial nerves, unlike the spinal ones, differ very much from one another in function, some being purely motor, others purely sensory, and only three of them mixed. They take origin from the grey matter within the brain.

Functions of the Brain.—Experiments similar to those described on page 135, show what a frog, deprived of its brain, is able to do by means of the spinal cord alone. The statement of what it can *not* do will give a rough idea of the functions of its brain. It must be explained that those actions are conveniently named **spon-**

taneous or **automatic** which start in a nerve-centre as the result of internal stimuli, and are not, like reflex actions, directly dependent on stimuli affecting afferent nerves. Such of these actions as depend on what we call 'will', are termed **voluntary**. A brainless frog is incapable of performing any voluntary actions, and apparently unable to effect any other kind of spontaneous action. It cannot feed, breathe, croak, swim, or crawl, either spontaneously or as a result of reflex action, nor can it even support itself upon its limbs. It may, therefore, be concluded that all the most complex activities of the body depend upon the brain, as do the possession of will, power of feeling, and intelligence. The same thing appears to be true of the higher animals, such as cat, dog, and rabbit, and of ourselves, with this limitation, that the spinal cord has a limited power of giving rise to spontaneous though not to voluntary actions.

Division of physiological labour in the Brain.—Even without observation and experiment, the complex structure of the brain would lead us to suspect that its work is subdivided among its various parts (p. 13).

The **bulb** gives rise, as will have been noticed, to the greater number of cranial nerves, and this is correlated with its very great functional importance. It acts (1) as a conductor of nerve impulses between the spinal cord and other parts of the brain; and (2) it contains a number of important nerve-centres, largely of reflex nature.

With regard to the bulb as a **conductor**, it need only be noticed that the nerve-fibres of its white matter *cross over* from one side to the other; from which it follows that injury of one side of the brain often results in paralysis of the opposite side of the body.

The chief **nerve-centres** in the bulb are those which work the movements of respiration, regulate the action of the heart, control the vaso-motor nerves, and bring about coughing, sneezing, and swallowing. The **respiratory centre** is situated just below the floor of the 4th ventricle, and its importance is shown by the .fact that, when it is injured, breathing at once stops, and death ensues. There are subordinate centres in the spinal cord which work under its control. Under ordinary circumstances, this centre appears to be **automatic**, working independently of impulses conveyed along afferent nerves, but varying its action according to the state of the blood circulating in the vessels of the bulb. The phenomena of asphyxia (p. 113) depend upon this. The blood in question quickly becomes impure, and this first stimulates the centre to increased activity, so that the movements of respiration become more violent in the attempt to get more oxygen and get rid of the accumulating carbon dioxide. The centre is then exhausted, as a result of these unusual efforts and the poisonous influence of the impure blood. The branches of the **vagus nerve** (L. *vagus*, wandering—in reference to its long course) which supply the respiratory organs, consist mainly of afferent fibres conveying nerve impulses to the respiratory centre, which accelerate, or retard, or even stop its action. The centre must be regarded as a **reflex** one in so far as its action is influenced by these afferent impulses.

The **mid brain** and **'twixt brain** act as a means of communication between the bulb and cerebellum on the one hand, and the cerebral hemispheres on the other. They also, in virtue of their grey matter, have to do with vision.

Functions of the Cerebral Hemispheres.—What the brain of a frog is able to do as a whole has already been stated (p. 140), and it appears that a very great deal can be done by the brain *minus* the hemispheres.

Frogs, from which the hemispheres have been carefully removed, have been kept alive for many months and subjected to observation and experiment. Such an animal, unlike one from which the entire brain has been removed, is able to support itself upon its limbs and to breathe normally. The circulatory organs do their work properly, and so do the digestive organs, *if food is placed in the mouth.* Complex actions, like leaping, crawling, swimming, and croaking, can all be carried out, but *only by reflex action* as the result of the application of external stimuli. Left to itself, however, the animal does not move, and shows no signs of intelligence. Nor is there any reason to suppose that it can 'feel', in the ordinary sense of the word. The conclusion is therefore reached that 'will', intelligence, and feeling or sensation depend upon the presence of the hemispheres. They, too, possess the power of stopping or **inhibiting** (L. *inhibeo*, I restrain) reflex movements that, when they are removed, always take place after certain stimuli have been applied. Thus, when the hemispheres are gone, the frog can unfailingly be made to crawl up a board on which it is placed, by slanting the board so that it would otherwise slip off. But place an uninjured frog on a board and do the same; the result is quite uncertain. Ten to one the animal leaps away.

One must, however, be cautious in applying to higher animals results obtained from the frog, and it must be remembered that the cerebral hemispheres work in the closest harmony with the other parts of the brain. But it is quite safe, nevertheless, to regard them as containing the supreme nerve-centres.

Cortex of the Hemispheres.—The grey matter making up the cortex has been mapped out into nerve-centres, some of which are 'motor' and some 'sensory'. The former have to do with initiating voluntary movements, and the latter are concerned with smell, hearing, sight, &c., as will be explained in the next chapter.

The central part of the **Sympathetic Nervous System** consists of two cords, situated one on each side of the backbone, and dilated at intervals into **sympathetic ganglia** or collections of nerve-cells. By means of cross-branches these ganglia are connected with the spinal and some of the cranial nerves. There are other important sympathetic ganglia besides those described. The sympathetic nervous system supplies the internal organs and blood-vessels, which it controls and regulates to some extent independently, but subject to the control of the brain and spinal cord.

General working of the Nervous System.—Examples have already been given of **reflex actions** for some of which the nerve-centres lie in the spinal cord, while for others they are situated in the brain. It remains to be said that a large number of *very complex* reflex actions are continually being performed, which may be called **acquired reflexes**, since they were, to begin with, only effected by constant attempts under the direction of the will. For instance, a boy sees a bun in a shop window, goes in, buys, and eats it. Here we have an extremely elaborate set of actions. *Sensations* of sight, started by the stimulation of the retina by the image of the bun focussed there, lead to changes in the grey matter of the brain of unknown but no doubt very complex nature. These again lead to the partly *voluntary* movements of walking into the shop, buying the bun, and carrying it to the mouth; involving the action of various nerve-centres, efferent nerves, and muscles. But the *details* of these actions, the various movements of legs, arms, and jaws are largely effected without any effort of the will as the result of external stimuli, *e.g.* contact with ground, bun, &c., and are therefore *reflex*. They are also *acquired* reflex actions—a new-born child could not carry them out.

CHAPTER X.

THE SENSE ORGANS AND SENSATION.

We are, when awake, in what may be termed a **conscious state**, that is, we are more or less aware of what is going on in and outside of our bodies. The opposite is the case in profound sleep, or during a dead faint, when we are said to be **unconscious**. Our awareness of current events is due to constant alterations or changes in our state of consciousness, to which the name 'feelings' or '**sensations**' (L. *sensus*, faculty of perceiving external objects) may be applied.

Thus we may speak of sensations of pain, hunger, warmth, contact, &c., while the various smells, tastes, sounds, and sights we smell, taste, hear, and see are examples of the same thing. **All sensations result from molecular changes in the grey matter of the brain**, preceded in the ordinary course of things by nerve impulses conveyed *to* the brain along sensory nerve-fibres. Thus, sensations of pain arise (p. 132) if, in a spinal nerve, the central stump of the cut dorsal root be stimulated. The part of the brain's grey matter involved in sensation is the cortex of the hemispheres.

Sensations are of two kinds, general and special. **General sensations** are those which, like hunger, thirst, fatigue, &c., give information about the condition of the body, but give no direct information about our surroundings. **Special sensations**, on the contrary, let us know what is going on outside ourselves, and here are included the 'five senses' of touch, taste, smell, hearing, and sight. These special sensations have a great deal in common, and it will be convenient to take them first. Their importance is obvious, as without them, or some of them, it would be impossible to live without constant aid from others. And again, the training of the special senses is of enormous importance in education, especially in its earlier stages, while without them communication between one mind and another would be, so far as we know, impossible.

All special sensations involve three things—(1) a **sense-organ**, the essential part of which consists of sense-cells or end-organs capable of being acted upon by one or more particular kinds of external stimulus; (2) a **sensory nerve**, the fibres of which are continuous with the sense-cells; (3) one or more **sensory nerve-centres** in the brain. The external agent or stimulus is in a state of vibration (p. 131), and it 'acts upon' the sense-cells by throwing their molecules into a state of vibration. The changes taking place in the rest of the sensory apparatus are also of the nature of molecular vibration. Just as in buildings there are special arrangements, such as knockers, bells, speaking-tubes, telephones, windows, &c., by means of which those inside can obtain more or less accurate knowledge of what goes on outside, so in the body, sense-organs are present for a similar purpose.

SENSE OF TOUCH.

The sense-organ of touch is the **skin**, together with the linings of the mouth and cavities of the nose. As to the **end-organs** of the skin a good deal of uncertainty exists, but there can be no doubt that some sensations of touch begin in **touch corpuscles** (fig. 83). These are ovoid bodies, about $\frac{1}{300}$ of an inch long, found in the papillae of the dermis (p. 123) in certain parts of the body. They are particularly numerous in the palms of the hands and soles of the feet, and it has been calculated that in the finger-tips about 50 of them occur within an area $\frac{1}{25}$ of an inch square. They are also abundant in the tip of the tongue. Such a corpuscle is an aggregate of numerous epithelial cells, and a couple of sensory nerve-fibres come into close relation with it. It may be emphasized here that **all the end-organs** belonging to the special sense-organs are **modifications of epithelium**.

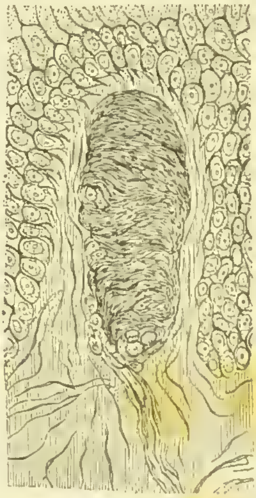


Fig. 83.—Magnified View of a Papilla of Skin, with a Touch Corpuscle.

The **sensory nerves** for touch are the trigeminal for most of the head, and the sensory parts of the spinal nerves for the rest of the body. These nerves branch up in the skin, and the trigeminal also sends branches to the lining of the nasal cavities and mouth, and to the pulp of the teeth (p. 59).

Sensations of Touch.—These result from the action of three kinds of stimuli—(1) contact, (2) pressure, (3) changes of temperature—which give rise to corresponding sensations.

(1) **Sensations of Contact** result when the skin touches, or is touched by, external objects. Vibrations are set up in the end-organs, as a result of which afferent impulses travel along the sensory nerves, and as a further and final result part of the grey matter of the cortex undergoes changes, and then, *but not till then*, the 'sensation' of contact arises. One or two important points with reference to this and all other kinds of special sensation require to be noticed here. (1) If, say, the book you are reading is touched with the tip of your left forefinger a sensation of contact follows, and, if asked to state *what* you feel and *where* you feel it, you would probably say that you experienced a feeling of smoothness, or it might be roughness, *in the finger-tip.* In other words, the sensation is supposed to take place *in the sense-organ.* But, in reality, the sensation takes place *in the brain*, and it is only as the result of experience that we learn to localize sensations in the sense-organs, and to realize that they teach us something about our surroundings. There is no reason to think that a new-born child understands the meaning of its sensations developed as the result of the action of various external stimuli. Take the case of an electric bell placed in an inner room and made to ring by pressing a stud on the front door. If a savage, who knew nothing of such arrangements, were placed in this room and the bell rang, he would not realize that the sound had anything to do with the outside of the house. But the same savage, after undergoing a certain amount of training, would soon learn, when he heard the same sound, to think at once of the stud, and to know that someone was pressing it. The bell would no longer be thought of. Call the house the body, the stud a sense-organ, the wire a sensory nerve, the bell a sensory nerve-centre in the brain, the sound a sensation, and the savage the mind, and the force of the illustration will appear. (2) It will now be understood that a sensation gives no information about external things, **except when compared by the mind with past experiences of the**

same kind. It naturally follows that if a *new* experience produces the same sensations as an *old* experience we shall be deceived, and think the new experience is only another sample of the old one. Thus, if the second finger is crossed over the first, and the two finger-tips are then applied to the tip of the nose and moved about a little, the result will be a distinct impression that the nose has *two* tips! This is because *one* small body is touching parts of the skin which, under ordinary circumstances, can only be touched at the same time by *two* small bodies.

Acuteness of the Sense of Contact in different regions. This has been estimated by taking a pair of compasses with blunted points and finding, for different regions, the smallest distance apart at which the points gave rise to *two* distinct impressions. Some of the results, in fractions of an inch are as follows:—Tip of tongue, $\frac{1}{24}$; tip of forefinger, $\frac{1}{12}$; red surface of lower lip, $\frac{1}{6}$; tip of nose, $\frac{1}{4}$; palm of hand, $\frac{5}{12}$; back of hand, $1\frac{1}{6}$; middle of thigh, $2\frac{1}{2}$. It appears from this that those parts are most sensitive which are actively used in touch. And, as might be expected, such parts are the best off as regards sensory nerves and end-organs. Another kind of sensitiveness goes with this, *i.e.* knowledge as to the exact position of the point touched.

(2) **Pressure Sense.**—Sensations of pressure arise when weights are laid upon the skin, and it is possible in this way to tell, within certain limits, which is the heavier of two given weights. The forehead and back of the hand are among the most sensitive parts in distinguishing small pressures, while the fingers and back of the foot appreciate most readily small differences between weights.

(3) **Temperature Sense.**—If the temperature of the skin is raised a sensation of 'heat' results, but if its temperature is lowered the sensation produced is one of cold. The parts most sensitive in this respect are: tip of tongue, eyelids, cheeks, lips, and neck.

There is reason to believe that sensations of contact, pressure, and temperature result from the stimulation of different end-organs and different sensory nerves. One reason for thinking this is that any particular part is not equally sensitive to the three different kinds of stimulus.

SENSE OF TASTE.

The **tongue** is the chief organ of taste in virtue of special sense-cells belonging to the stratified epithelium by which it is covered. The surface of the tongue is raised into three kinds of minute projections or papillae —(1) **Filiform papillæ** (L. *filum*, thread; *forma*, shape) which are the most numerous. They are cylindrical in shape, and about $\frac{1}{12}$ of an inch long. (2) **Fungiform papillæ**, shorter, broader, and much less numerous than the preceding. They are somewhat mushroom-shaped, hence their name (L. *fungus*, mushroom; *forma*), and may often be detected as bright red spots. (3) **Circumvallate papillæ**, which are the largest and least numerous kind, there only being about a dozen of them, arranged in the form of a backwardly-pointing V on the back of the tongue. Each is surrounded by a deep groove, and this again by a ridge (L. *circum*, around; *vallum*, wall).

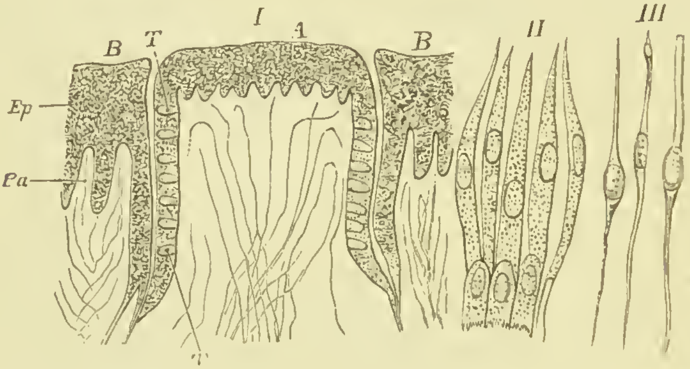


Fig. 84.—Section of Circumvallate Papillæ of the Tongue—highly magnified.

I A, Section of the central papilla; B B, section of the surrounding elevation; *Pa*, papilla of the true skin; *Ep*, layer of stratified squamous epithelium; T, taste buds. II and III represent very highly magnified views of cells of the taste buds.

The end-organs of taste are slender **taste-cells** (fig. 84), contained in oval **taste-buds** imbedded in the epithelium of the fungiform and circumvallate papillæ.

The **sensory nerves** for taste are usually considered to be (1) a **lingual branch** of the **trigeminal**, supplying the front part of the tongue; (2) the **glosso-pharyngeal nerve**, supplying the back part of the tongue. The taste-cells are probably continuous with fibres of the latter.

Sensations of Taste.—Some of what we call 'tastes', in the ordinary sense of the word, are due to the fact that the tongue is also an organ of touch, while others, especially those called 'flavours', depend more or less on the sense of smell. A person suffering from a cold in the head often complains that his food is 'tasteless', the fact of the case being that he can taste but not smell as usual. That it is possible to smell the food in the mouth will be realized if it is remembered that the nasal cavities communicate with the pharynx by means of the posterior nares (p. 60). 'Burning' tastes are examples of tastes depending on the sense of touch.

From a physiological standpoint the only **true tastes** are those known as **sweet**, **bitter**, **salt**, **sour** or **acid**, and **alkaline** (taste of saltpetre). Tastes of this kind cannot arise unless the substances producing them are in a state of **solution**. This can easily be shown by wiping the surface of the tongue quite dry with a handkerchief and placing a crystal of sugar upon it. No sweet taste will be experienced until the tongue gets damp again and the sugar begins to dissolve.

There are very probably different end-organs for different tastes, as in most cases the tip of the tongue is most readily affected by sweet and saline substances, its sides by acids, and its back by bitters. This view is further supported by the fact that by chewing the leaves of a certain Indian plant (*Gymnema sylvestre*) the power of tasting sweets and bitters is for the time being lost, while other tastes are unaffected.

Differences of opinion exist as to whether the lingual or glosso-pharyngeal is the nerve of taste, or whether both assist in this sense. Disease of one trigeminal leads to loss of taste in the corresponding half of the tongue, but no such result follows disease of the glosso-pharyngeal. From this it may be concluded that the former is the true nerve of taste, and the glosso-pharyngeal fibres which supply taste-cells probably belong to it. It is no unusual thing for fibres from the root of one nerve to pass over into another nerve.

The tongue is not the only organ of taste, for taste-buds are also found in the epithelium covering the soft palate.

What has already been said about sensations arising in the brain, as the result of vibrations set up in sense-cells and sensory nerves (p. 146), applies to taste as well as to touch. Substances in solution are known to be in a state of molecular vibration, and this is communicated to the taste-cells. The organ of taste has been aptly described as a sentinel placed at the beginning of the digestive tube.

SENSE OF SMELL.

The **nose** is usually called the organ of smell, and this is true in so far as part of the epithelium lining the nasal cavities contains the olfactory end-organs. Each nasal cavity communicates with the exterior by a **nostril** or **external naris**, and with the pharynx at the back by one of the posterior nares. The cavity is largely blocked up by the three **turbinated bones** which project from its outer side (fig. 85). It is lined by mucous membrane, the extent of which is increased by the presence of these bones. The lower part of the cavity merely serves as a passage for the breath, and is therefore called the **respiratory portion**, while the upper part constitutes the **olfactory portion**. This latter region is lined by yellowish epithelium, containing numerous slender **olfactory cells**, which are the end-organs for smell.

The **sensory nerve** for smell is the **olfactory**, the branches of which pass through the holes in the cribriform plate, and divide up in the olfactory mucous membrane (fig. 85, 1), their fibres ultimately becoming continuous with the olfactory cells. The lining of each nasal cavity is also supplied by branches of the trigeminal.

Sensations of smell are produced when certain gases or vapours come into contact with the epithelium lining the nasal cavities. What are called 'smells' in ordinary language are not all of similar physiological nature (cp. p. 149). For example, pungent smells, like that of smelling-salts, are brought about by the stimulation of end-organs connected with the fibres of the trigeminal, and may be looked upon as due to a refined sense of touch. True smells, stimulating the olfactory cells, may be classified as **fragrant or the contrary**. To the former belong the odour of musk, lavender, and the like; to the latter, putrid and other unpleasant odours. 'Sniffing', in order the better to perceive any given smell, draws the odorous gas or vapour into the nasal cavities, where it comes into contact with the end-organs of smell.

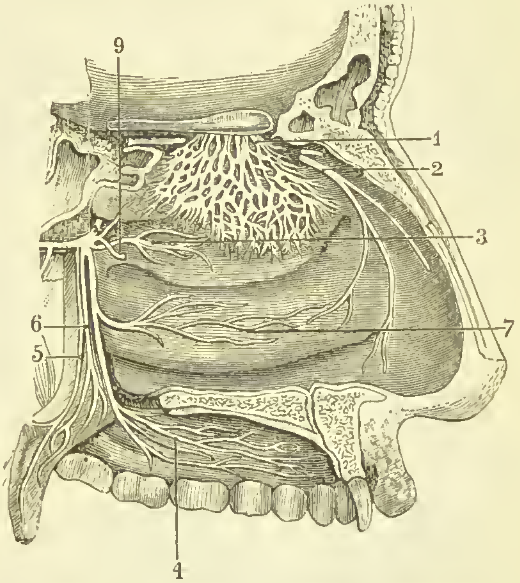


Fig. 85.—Distribution of Nerves over interior of Left Nasal Cavity, outer wall.

1, Branches of nerve of smell—olfactory nerve; 2, 3, 7, 9, trigeminal branches to nasal cavity; 4, 5, 6, ditto to palate.

The organ of smell guards the beginning of the breathing passages, and warns us against foul-smelling air, which is generally more or less injurious to health. This is one reason why we should breathe through the nose, another being that the air is both filtered and warmed in passing through the complicated nasal cavities, the openings into which are protected by stiff hairs. In this way a good deal of dust can be kept out of the windpipe and its branches, and there is less danger of chilling, with cold, cough, or sore throat as the result. The organ of smell is also a check on the digestive organs, preventing us, *e.g.*, from eating such harmful substances as putrid meat. The 'flavour' of food (p. 149) is due more to smell than taste.

SENSE OF HEARING.

It will have been remarked that the delicate end-organs of touch, taste, and smell have a more or less sheltered position, and the same is true in a much greater degree for the complicated and extremely delicate structures which make up the essential part of the organ of hearing. These structures are, in fact, situated within a cavity hollowed out in the densest part of each temporal bone.

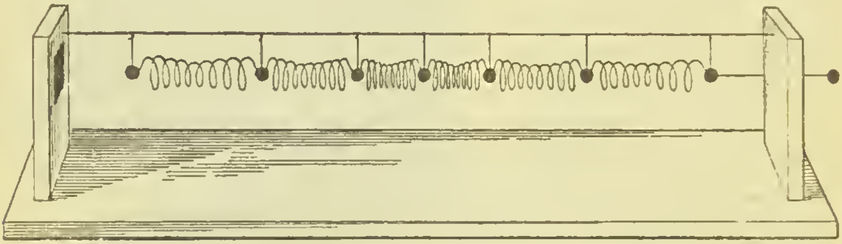


Fig. 86.—Mode of Propagation of a Pulse.

The **stimulus** giving rise to sensations of hearing consists of **to-and-fro vibrations**, or 'pulses' of the air, set up by sounding bodies, such as bells, tuning-forks, or the larynx. Fig. 86 is a piece of apparatus designed to explain the meaning of a 'pulse'. A number of wooden balls, with pieces of spiral spring between them, hang from a wire. If the first ball is struck the first piece of spring is compressed, and in lengthening again pushes the first ball backward and the second ball forward, thus compressing the second piece of spring, and so on. In this way a to-and-fro vibration travels on till the last ball is affected. Something like this happens when a sounding body, say a straight spring held in a vice (fig. 87), is made to produce a sound. It vibrates to and fro, and this vibration travels from it, through the air, as **sound-waves.**

The **organ of hearing** consists of (1) a sound-conducting part, by means of which vibrations in the air are transmitted to (2) the essential auditory structures, containing the end-organs of hearing and supplied by the **auditory nerve,** which is the **sensory nerve** for this sense.

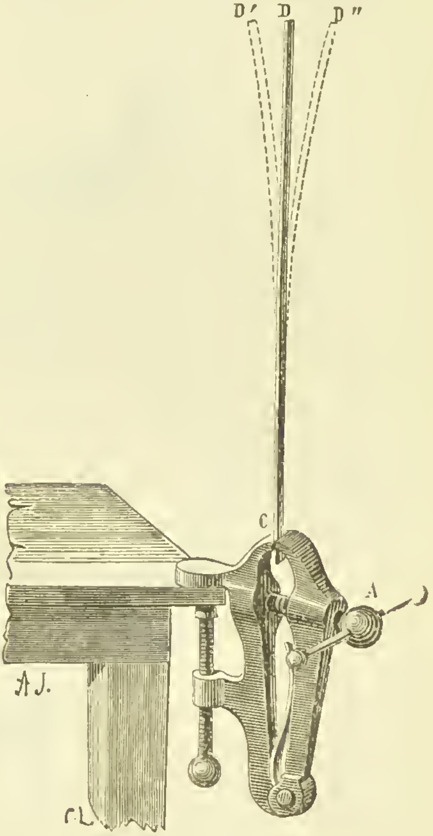


Fig. 87.—Vibration of Straight Spring.

The free end D assumes alternately the positions D′ and D″. Its lower end C is fixed in a vice A.

The **Sound-conducting part** (fig. 88) is necessary owing to the fact that the essential parts are placed so far from the surface of the body. It includes the regions usually known as the external and middle ears. (1) The **external ear** consists of (*a*) the outer flap, to which the name 'ear' is given in ordinary language, while technically it is known as **concha** (L. for shell), and (*b*) a slightly-curved passage, the **external auditory meatus** (L. *meatus,* passage), which runs into the head for a distance of rather more than an inch. (2) The **middle ear** consists of the **tympanic cavity** (L. *tympanum,* drum), or 'drum' of the ear, and of structures connected with it. This cavity is separated by a firm **tympanic membrane** from the external **auditory meatus.** It is largely bounded by the temporal bone, and communicates with the pharynx by means of the **Eustachian tube**. Three little bones (fig. 89) the **auditory ossicles** (L. *ossiculum*, little bone), named, from their shape, hammer, anvil, and stirrup, stretch across the drum. The handle of the hammer is fixed to the tympanic membrane, while the foot-plate of the stirrup is fixed in the inner wall of the tympanic cavity.

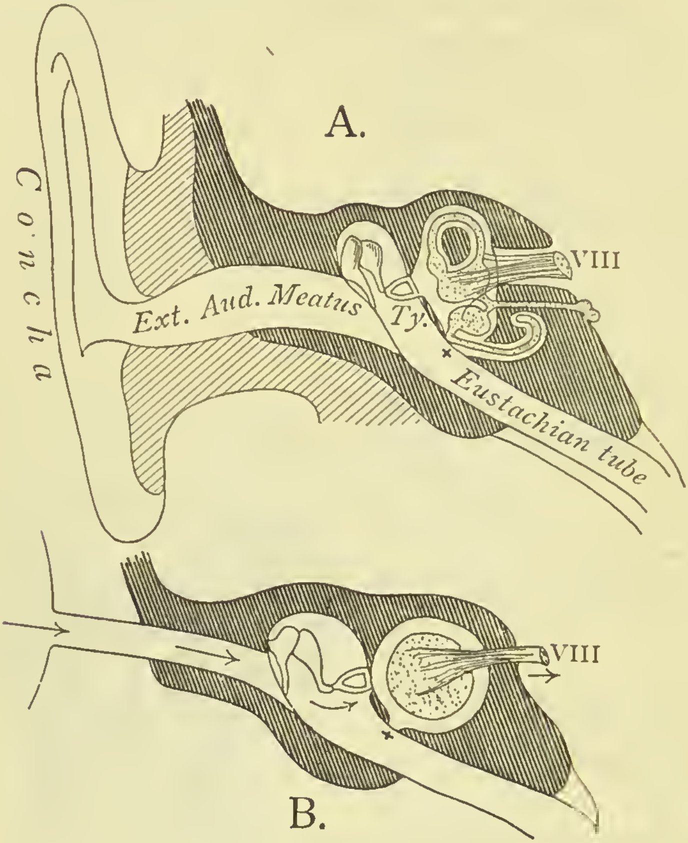


Fig. 88.—Diagrams of Auditory Organs (natural size).

Parts cut through are shaded, the close shading indicating the temporal bone Membranous labyrinth dotted. *Ty*, Tympanic cavity; × is placed by fenestra rotunda; viii, auditory nerve. Arrows indicate direction in which sound-waves and resultant nerve impulses pass. A is after Schwalbe, and B is a still simpler diagram.

The **Essential Auditory structures** or **Internal Ear** consist of a bag filled with clear fluid (**endolymph**) and contained in a cavity larger than itself within the temporal bone. This cavity is also filled with fluid (**perilymph**). It will make matters easier if the bag is first thought of as being simple in shape (fig. 88, B). The containing cavity is separated by bone from the drum except in two places, known as 'windows' or **fenestræ**, which are filled up with membrane, or otherwise the perilymph would escape into the drum. The upper window, on account of its shape, is known as the **fenestra ovalis** (L. for oval window), and the stirrup foot-plate is fixed into its membrane. The lower window, being round, is called the **fenestra rotunda** (L. for round window). It remains to be added that the bag is lined by epithelium, which at certain spots contains numerous slender **auditory cells** (fig. 90), each provided with one or more '**auditory hairs**' projecting into the endolymph, in which are suspended minute calcareous particles or **otoliths** (Gk. *ous, ōtŏs*, ear; *lithŏs*, stone). The **auditory nerve** runs from the brain to the bag, and its fibres in all probability become continuous with the auditory cells.

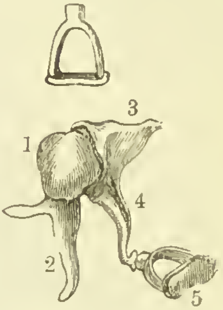


Fig. 89.—Ear-bones.

1, 2, Hammer; 3, 4, anvil; 5, stirrup, the figure being placed by the foot-plate which fits into the fenestra ovalis. Another view of the stirrup is given above.

We are now in a position to understand how **Sensations of Sound** are started. Sound waves, collected to some extent by the concha, travel along the external auditory meatus, and cause the tympanic membrane to vibrate. By means of these vibrations the auditory ossicles are moved, and the foot-plate of the stirrup pulls the membrane of the fenestra ovalis backwards and forwards, so that waves are set up in the perilymph. From this vibrations pass through the wall of the bag and affect the endolymph, by the movements of which the auditory hairs and cells are caused to vibrate so as to stimulate the fibres of the auditory nerve. The impulses, passing along the nerve to the brain, affect the grey matter making up the sensory centres for hearing situated in the cerebral cortex, and sensations of hearing are the result. The path taken by the vibrations involved in this sense is therefore as follows:—concha—

external auditory meatus—tympanic membrane—auditory ossicles—perilymph—endolymph—auditory hairs—auditory cells—auditory nerve—brain. Sounds can also reach the auditory bag by transmission through the bones of the head. This may be proved by closing the ears with cotton-wool, and then holding between the teeth the handle of a vibrating tuning-fork, when the sound given out will be heard distinctly. A few other points need mention.—(1) The **Eustachian tube** indirectly places the drum in communication with the external air, so that this presses with the same force on both sides of the tympanic membrane, which would otherwise bulge outwards or inwards, according to circumstances, and lead to giddiness or other unpleasant sensations. (2) The membrane filling the **fenestra rotunda** bulges in or out as the membrane of the fenestra ovalis is pulled out or pushed in, and so the perilymph is prevented from agitating the auditory bag too violently. (3) The **otoliths** are not found in all parts of the endolymph, but in a kind of mucous substance which is present in the region of the auditory hairs. This substance, perhaps, prevents the hairs from vibrating too much, while the otoliths may help to make them vibrate.

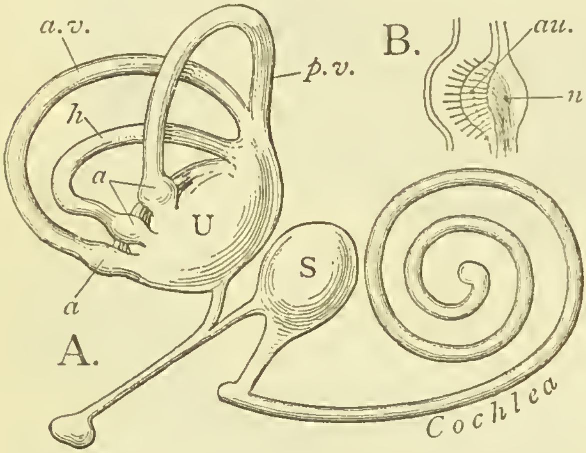


Fig. 90.—Membranous Labyrinth (much magnified).

A, Right labyrinth, seen from the inner side; U, utriculus; S, sacculus; *a.v.*, *p.v.*, and *h*, anterior vertical, posterior vertical, and horizontal semicircular canals; *a a*, ampullæ; B, longitudinal section, through an ampulla; *au*, auditory cells; *n*, fibres of auditory nerve.

So far the auditory bag has been described as if it were of simple construction. This, however, is by no means the case, as its name of **membranous labyrinth** indicates, and as will be seen from fig. 90. It consists of (1) a **utricle** (L. *utriculus*, little bag), and (2) a **saccule** (L. *sacculus*, little bag), only connected by a Y-shaped tube—and also of (3) three curved **semicircular** canals connected with (1), and (4) a spirally-coiled tube, the **cochlea** (Gk. *cŏchlias*, snail shell) connected with (2). One end of each semicircular canal is swollen into an ovoid **ampulla** (L. for flask). **Auditory cells** occur in a patch in the utricle, a patch in the saccule, on a ridge in each ampulla (fig. 90), and in the cochlea, where their arrangement is very complex.

The cavity containing the labyrinth is of the same general shape, and it is bounded by a layer of specially hard bone, from which the softer bone outside can be chipped away, leaving what is known as the '**bony labyrinth**' (fig. 91). This contains the membranous labyrinth suspended in perilymph.

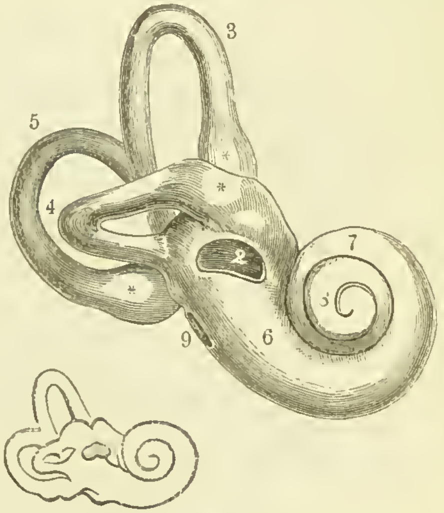


Fig. 91.—Bony Labyrinth of the right side; the upper figure magnified, the lower of the natural size.

2, Fenestra ovalis; 9, fenestra rotunda; 3, 4, 5, bony semicircular canals with ampullæ * * *; 6, 8, 7, bony cochlea; utricle and saccule lodged in central mass termed "vestibule".

SENSE OF SIGHT.

The organ of sight or **eye** has to be near the surface, in order to perform its functions, but is protected in an elaborate way by its position, and by various accessory structures. The **orbit**, in which the eyeball is contained, is extremely strong, and the front of the eyeball is protected by the **eyelids** and **eyelashes**, while the **eyebrows** prevent sweat from running down into the eyes.

The eyeball is a good deal smaller than the cavity of the orbit, and the spare space is partly filled up by soft fat, which acts as a protective packing, and also allows the eye to be moved by means of its special **muscles**. The front of the eye is kept clean by the secretion of the **tear-gland**, which is situated in the upper and outer part of the orbit, and opens by small ducts in the inner side of the upper eyelid. It resembles a salivary gland in structure, and its secretion, after washing the front of the eye, passes into a small **tear sac** situated near the inner corner of the eye, by means of a minute duct opening on the edge of each eyelid close to the inner corner. From the tear sac the 'tears', under ordinary circumstances, pass down by a **tear-duct** into the nasal cavity.

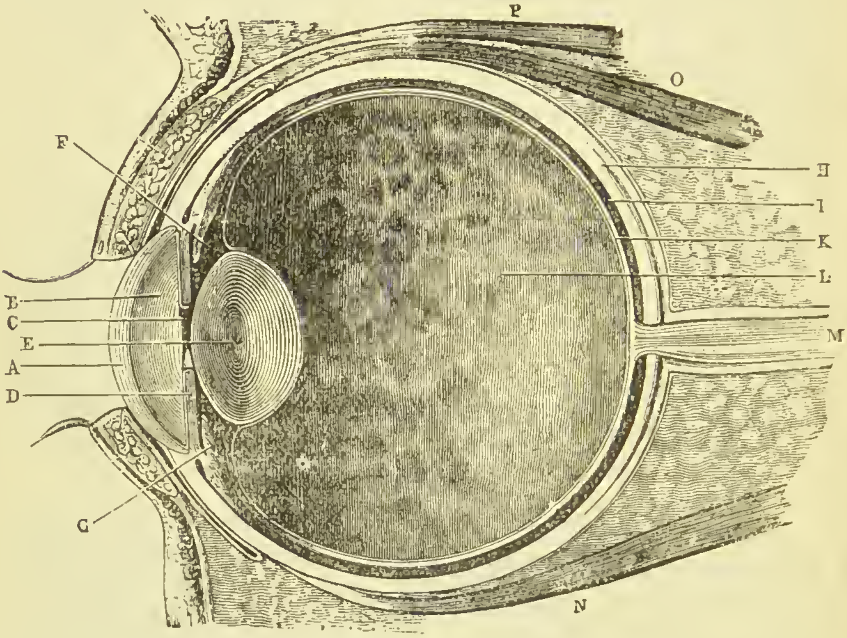


Fig. 92.—Longitudinal Vertical Section of the Eye.

A, Cornea; B, aqueous humour; C, pupil; D, iris; E, lens; F, suspensory ligament; G, ciliary process; H, sclerotic; I, choroid; K, retina; L, vitreous humour, outside which the hyaloid membrane is indicated by a fine white line; M, optic nerve; N, inferior rectus; O, the superior rectus muscle; P, muscle which raises the upper eyelid.

Structure of the Eyeball (fig. 92).—The practical examination of a sheep's eye by cutting into it will show that it consists of a firm wall, enclosing softer structures in somewhat the same way as the skin of a ripe gooseberry surrounds a semi-fluid pulp. This wall consists of 4 coatings of very different thickness and nature. (1) The outermost coat, known as the 'white of the eye' or **sclerotic** (Gk. *sklēros*, hard) is of protective nature, and consequently thick and tough. In front the eyeball is more strongly curved than elsewhere and here a circular piece of the sclerotic is transparent, and is known as the **cornea** (L. *corneus*, horny), which may be regarded as a window by which light enters the eye. (2) Within the sclerotic comes a thinner **choroid** coat (Gk. *chŏriŏn*, membrane; *eidŏs*, resemblance), containing numerous blood-vessels, and a great deal of pigment. This coat does not line the cornea, but in the front of the eye becomes continuous with a flat muscular partition, the **iris** (L. for rainbow), by which the eye is divided into a smaller **anterior chamber**, and a very much larger **posterior chamber**. This partition is pigmented, and is the grey or blue or brown part which gives to the eye much of its characteristic appearance. In the centre of the iris there is a circular hole, the **pupil** (L. *pupilla*, has same meaning), through which light can pass into the interior of the eye. The size of this varies according to circumstances, and it may be seen as a black patch in the centre of the iris. It looks black because the dark interior of the eye is seen through it. The choroid is

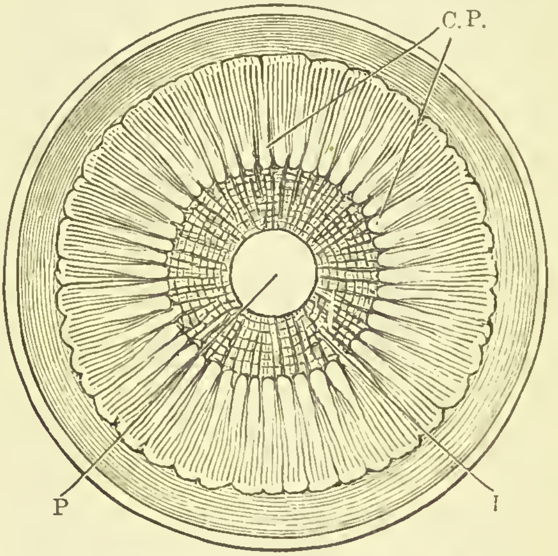


Fig. 93.—Front of Eyeball viewed from behind, and showing Ciliary Processes (C. P.), Iris (I), and Pupil (P).

thickened at the back of the iris, and raised into a number of radiating ciliary processes (fig. 93). (3) A delicate transparent membrane, the **retina** (L. *rete*, net), constitutes the third and most important coat of the eye. It extends on to the back of the iris, but only that part of it lining the posterior two-thirds of the eye is of physiological importance. If this part of the eye is looked at from inside a small, yellowish depression will be seen exactly in the middle (fig. 94). This is the **yellow spot**, and a little to the inner side of this there is a small area, the **blind spot**, from which fibres and small blood-vessels can be seen to radiate. The retina can easily be separated from the choroid *except* at this spot, the reason being that the optic nerve here becomes continuous with the retina after passing through the sclerotic and choroid. The fibres of the optic nerve branch up in the retina, and form a layer in that part of it *furthest away from the choroid.* Fig. 95 represents a section through the thickness of the retina, immensely magnified. Beginning on the outside (*i.e.* next the choroid), the following structures are seen:—(*a*) A layer of cells containing pigment. (*b*) A layer of modified epithelium made up of elongated cells called the **rods** and **cones**. These are the **end-organs of sight**. (*c*) Several layers of less importance. (*d*) A layer of **nerve-cells**. (*e*) A layer made up of the **fibres** of the **optic nerve**. The most important point to grasp is that *the rods and cones are connected* in a round-about way, by means of the intermediate structures, *with the fibres of the optic nerve.*

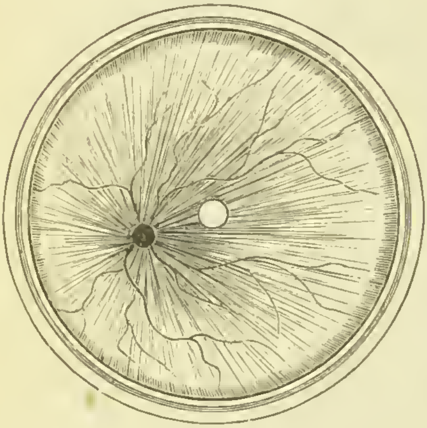


Fig. 94.—Back Half of Eyeball.

(4) The fourth and last coat of the eyeball is the

thin, transparent, highly-elastic **hyaloid membrane** (Gk. *hyalos*, glass; *eidŏs*), inside the retina. This membrane adheres closely in front to the ciliary processes, so that it is thrown into folds, and then splits into anterior and posterior layers, known as **suspensory ligaments** (fig. 98) because they are continuous with a capsule in which is suspended the **crystalline lens**. This is a firm, glassy, elastic body, looking like a small magnifying-glass, and possessing convex front and back surfaces. It is therefore said to be **biconvex** (L. *bis*, twice; *convexus*, arched). The anterior chamber in front of the lens is filled with a watery liquid, the **aqueous humour** (L. *aqua*, water; *humor*, moisture); and the posterior chamber behind the lens contains a transparent jelly, the **vitreous humour** (L. *vitrum*, glass; *humor*).

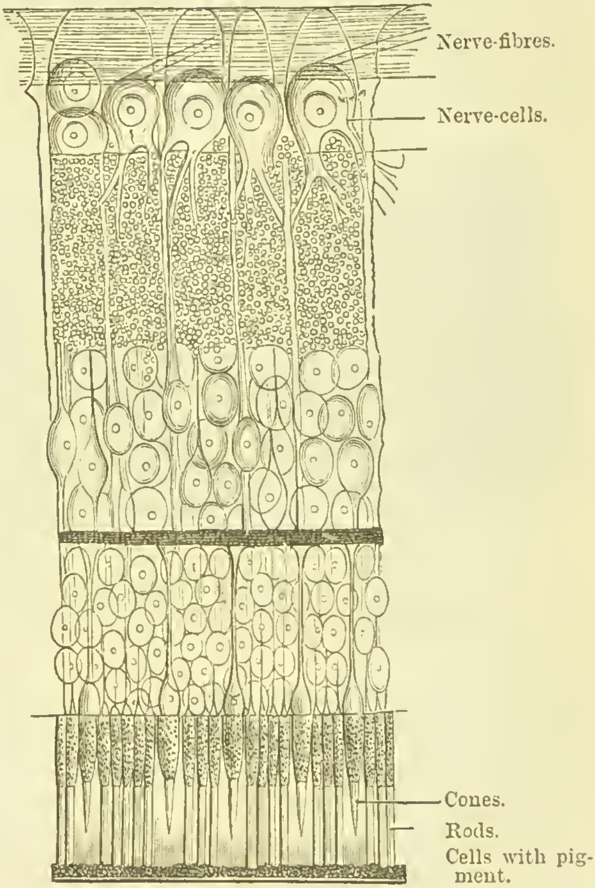


Fig. 95.—The Microscopic Structure of the Retina.

Sensations of Sight result when the rods and cones are acted upon by light, which is the special stimulus for this sense. **Light** is supposed to consist of vibrations of a particular kind, traversing an impalpable substance,

ether[1] (L. *aether*, sky), which is supposed to pervade space. Light does not, like sound, depend on the presence of air, and hence, by means of the sense of sight, we are able to obtain information about bodies at vast distances away from the earth. The eye not only enables us to distinguish between degrees of brightness and kinds of colour, but also to distinguish the *shape* of surrounding bodies. It is, in fact, an optical instrument presenting many points of resemblance to a photographer's camera, and the retina may be regarded as a sensitive screen upon which images of surrounding objects are thrown, mainly owing to the action of the crystalline lens.

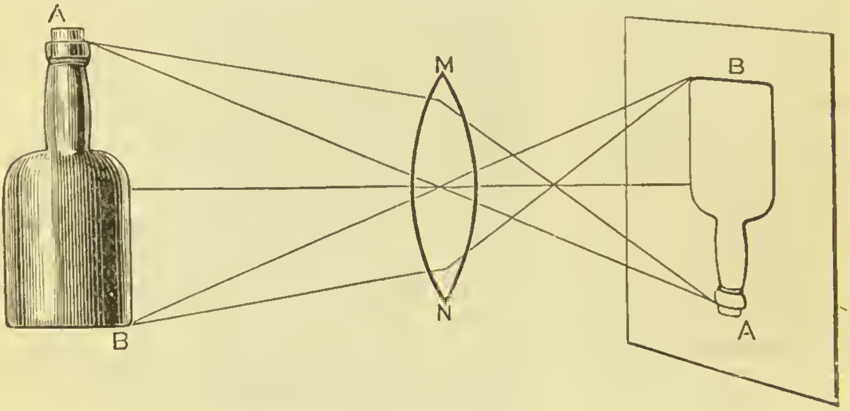


Fig. 96.—Formation of Inverted Image on Screen by Biconvex Lens.

A B, a bottle, an inverted image of which, B A, is formed by the lens M N. The lines represent the course of some of the light-rays passing from the object through the lens.

Action of Lenses.—The waves or undulations which constitute light travel in straight lines, and are called 'light-rays'. A 'sunbeam' passing through a chink into a room is a collection of such rays, the course of which is made visible by means of the dust which they illuminate. A **lens** (L. for lentil) is a piece of glass or other transparent solid with two surfaces, one of which, at least, is curved. If both are curved outwards the lens is **biconvex**. Take an ordinary magnifying-glass, which is a lens of this kind, hold it up to the window, and put a piece of white paper behind it. It will then be found that, *at a certain distance*, a little picture of the objects outside the window will be clearly outlined on the screen, but up-side-down. This is illustrated by fig. 96. The rays of light in fact are bent or **refracted** (L. *refractus*, bent) into a new path so as to bring this about. A photographer's camera is arranged on this principle, the lens being fitted into the front of a dark box, at the back of which the screen is placed. The **eye,** again, may be regarded as a **spherical camera** with a lens in front, and a curved screen, the retina, behind (fig. 97). Since the cornea, aqueous humour, and vitreous humour assist the lens in refracting the rays so as to form images, all four together may be called the 'refracting structures' of the eye. Light-rays are **reflected** (L. *reflecto*, I turn back) from the surfaces of bodies just as tennis-balls rebound from a wall, and it is owing to such rays that we see objects which are not (like the sun, stars, flames of lamps, &c.) self-luminous. Thus, the moon is seen because the rays of the sun are reflected from it. The **pigment** of the eye prevents the light which enters from being reflected from one part to another, which would produce a 'dazzling' effect, and prevent clear vision.

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[1] Not to be confused with the volatile substance of the same name sold by chemists!

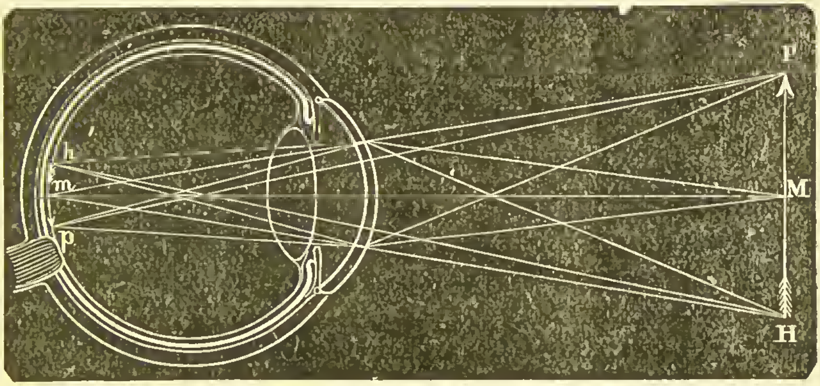

Fig. 97.—Formation of Image on the back of the Eyeball.

Rays of light proceed from the points P, M, H of the arrow and are focussed by the lens and humours of the eye to form an image, *p*, *m*, *h*, which is smaller than the object and inverted.

Accommodation.—By experimenting with a lens and sheet of paper it will soon be found that clear pictures of *near* objects can only be formed *when the paper is further from the lens* than is necessary for *distant* objects. In a photographer's camera the distance between lens and screen can be altered at pleasure, according to the distance of the objects to be taken. Such an arrangement would be very inconvenient in the eye, and is not the one used. But in the camera another method is possible. Suppose it arranged so as to take *distant* objects, and that it is required to take a *near* object *without altering the distance between lens and screen.* This can be done by *using a lens with one or both sides more strongly curved.* Now a healthy human eye is so arranged that, *when no effort is being employed,* distant objects are clearly seen, and 'accommodation' to near objects must in this case be managed not only without altering the distance between lens and screens (*i.e.* retina) but also *without changing the lens.* This, at first sight, seems to be impossible; but the lens of the eye is not rigid like a piece of glass but elastic, so that *its shape can be altered,* which comes to the same thing as changing the lens of a camera. When we are looking at distant objects the lens is *kept on the stretch* by its suspensory ligaments. If these could be slackened the lens, being elastic, would become more convex, and nearer objects would be clearly seen. In looking at objects within a distance of 71 yards, we are conscious of a feeling of *effort.* This is because we are using a muscle, the **ciliary muscle**, which accommodates the eye to near objects by slackening the suspensory ligaments. This is explained by fig. 98. The ciliary muscle takes origin from the circular junction of cornea and sclerotic, and is inserted into the thickened part of the choroid, which bears the ciliary processes, to which it must be remembered the suspensory ligaments are closely attached. When this muscle contracts the choroid is drawn forward, the suspensory ligaments are slackened, and the front of the lens becomes more convex. The nearer the object that is being looked at the greater the contraction. That the choroid *is* pulled forwards as described has been proved, for just-killed animals, by sticking a long needle into the eyeball (see fig. 98) so that its *point* is lodged in the choroid. The ciliary muscle is then made to contract by stimulating the nerves which supply it, and the *head* of the needle is seen to move *backwards*, which means that its point and the choroid move *forwards.*

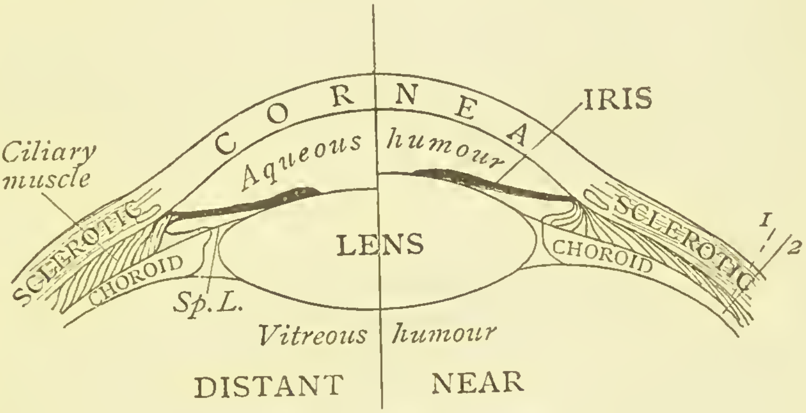

Fig. 98.—Diagram to illustrate Accommodation.

On the right side the adjustment for near objects is shown, and on the left that for distant objects. 1, Position of needle pushed through into choroid coat before accommodation; 2, position of the same after accommodation.

That the shape of the lens-front *does* alter during accommodation is easily proved by holding a candle on one side of the face of another person, in a darkened room. Three images of the candle-flame can then be seen in the front of the eye;—(1) a bright, upright image from the front of the cornea, (2) a similar but larger and rather duller image from front of lens, (3) a small, dim inverted image from back of lens. When the eye is being accommodated for near objects (1) and (3) remain unaltered, but (2) gets smaller. This proves that the front of the lens is altering its shape and becoming more convex.

The **iris** regulates the *amount* of light which enters the eye, undergoing changes by which the pupil is made larger or smaller, as the case may be. When the eye is exposed to a bright light the pupil becomes very small, while in a dim light it is of considerable size. In a camera a similar end is attained by plates of metal called *diaphragms*, each of which is perforated by a hole. One of these plates is put in front of the lens. The iris is partly made up of **circularly-arranged muscle-fibres**, and when these contract the pupil narrows. Enlargement of the pupil is due to **radially-arranged elastic fibres** which are put on the stretch when the pupil is narrowed, and come into play when the muscle-fibres cease to contract. Narrowing of the pupil takes place when *near* objects are looked at as well as when the light is strong, the object being to prevent light-rays from entering, which would not help to make a distinct picture.

The alterations in size of the pupil are brought about by reflex action—the **stimulus** being light, the **afferent nerve** the optic, the **nerve-centre** part of the grey matter of the mid brain, and the **efferent nerves** (*a*) oculomotor for narrowing, (*b*) sympathetic for enlargement.

Proofs that the Rods and Cones are the End-organs for Sight.—These structures resemble what are known to be end-organs in other cases, and they are connected with the optic nerve-fibres. But they are *turned away from the light*, and definite proof of their function is therefore necessary. One argument is derived from the **blind spot** (p. 167), where rods and cones are entirely absent. Closing one eye look fixedly at the **a** in fig. 99, when the **A** will also be seen. Now slowly move the book first towards then away from the eye. It will be found that at a certain distance the **A** disappears from view. It can be proved that in this position the image of **A** falls on the blind spot, which, therefore, is not sensitive to light, and receives its name on that account. The fibres of the optic nerve are more numerous here than elsewhere, and it is therefore proved that *they* are not the structures acted upon directly by light, while the probability of the rods and cones being the end-organs is increased. Further, the **yellow spot** is the area where sight is most acute, and here the retina consists of cones only, and of nerve-fibres directly continuous with them. Such fibres are *less* abundant here than elsewhere. It would seem from this that the cones at any rate are probably end-organs for sight, and as some animals possess no cones but only rods, it seems reasonable to suppose that these also are visual end-organs. The evidence described, taken collectively, is sufficient proof as to the functions of the rods and cones, and confirmation is given by a simple experiment. If a white surface is looked at in a dark room, where the only source of light is a candle placed on one side of the head, a sort of branching figure will be seen, which moves as the candle is moved. This figure is the *shadow* of the blood-vessels of the retina, and it must be seen by means of end-organs placed *behind* these vessels. This is the position of the rods and cones. We must, therefore, conclude that light, after passing through the cornea, aqueous humour, lens, vitreous humour, and hyaloid membrane, traverses the transparent retina and stimulates the rods and cones, which again affect the fibres of the optic nerve so that afferent impulses are set up. These travel to the brain, and in part of the cortex of the hemispheres changes take place leading to visual sensations.

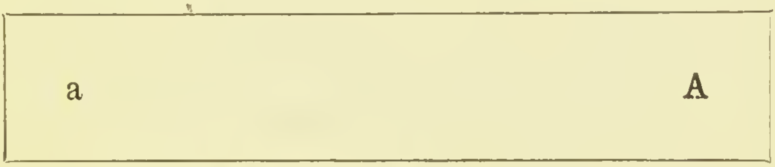

Fig. 99.—To show the "blind spot".

The **movements of the eyeball** are brought about by six band-like muscles. Four of these, the **rectus** muscles (L. for straight) arise close together from the back of the orbit and are inserted into the sclerotic above, below, to the inner side, and to the outer side, being respectively known as *superior*, *inferior*, *internal*, and *external* rectus muscles. The two former are shown in fig. 92. Their respective use is to move the eyeball up, down, inwards, and outwards. The two remaining muscles are the *superior* and *inferior* **oblique**, by which twisting movements are given to the eyeball. The former arises from the back of the orbit, runs along its inner side, and then passes through a little fibrous loop to be inserted into the upper side of the eyeball. The inferior oblique takes origin from the inner wall of the orbit, runs under the inferior rectus, and is inserted into the outer side of the eyeball.

Long Sight and Short Sight.—Most old people and a fair number of young ones are 'long-sighted', by which is meant that the eye has to be accommodated even to distant objects by means of the ciliary muscle, while by *no* effort can very near objects be clearly seen. In an *old* person the meaning of this commonly is, that the lens has lost some of its elasticity, and cannot, therefore, be made convex enough for near work. In *young* persons the probability is that the eye is too short from front to back. The remedy, in either case, is the use of spectacles with *convex* glasses, which, in the first case, make up for the deficiency in the lens, and in the second, so add to its power that the shortness of the eye is got over.

Short-sighted eyes are *too long* from front to back, and are therefore permanently accommodated for *near* objects. Efforts of accommodation are of no use for distant objects, and, indeed, only focus the eye for *still nearer* objects. The remedy is the use of *concave* glasses, by which the power of the lens is diminished, and which comes to the same thing as substituting a weaker lens suited for the unusual length of the eye.

General Sensations.—It is only necessary to add to what has been said on p. 144, that **pain**, one kind of general sensation, results when the end-organs of a sensory nerve are stimulated too strongly, or when the nerve itself is stimulated. This is not true, however, for the nerves of sight and hearing with their end-organs, and perhaps not for those of smell and taste. If, for example, the optic nerve is injured, a sensation of light and not of pain is the result. The name **Muscular Sense** is given to the *sensations of effort*, experienced when muscles are used. It is mainly by this sense that we estimate the amount of a weight held in the hand, and in doing so we move the hand up and down, so as to bring numerous muscles into action. We are thus better able to judge of the effort put forth. The relative weights of two objects can be determined with considerable accuracy by balancing them one against the other in the two hands. It is known that muscles are supplied with sensory as well as with motor nerves, and the former are no doubt connected with the muscular sense.

CHAPTER XI.

PRACTICAL WORK.

I. CHEMISTRY.

An elementary knowledge of apparatus, &c., is assumed. Directions for preparation of oxygen, &c., have been given in the body of the book. For physiological chemistry see Section IV. Students who have not been through a chemical course are strongly recommended to read Harrison and Bailey's *Chemistry for All* (Blackie).

II. SKELETON AND MODELS.

1. **Skeleton.**—(1) A human skeleton should be very carefully studied, and its parts *drawn in an unruled notebook.* A medical half-set will answer most purposes, but for teaching a class a fully articulated skeleton is very desirable. In any case a bisected skull to show interior will prove a valuable addition. It is a good plan to mark the boundaries of the bones with a thin line of red enamel paint. Skeletons or parts of them can be obtained at a reasonable price from H. Meller, anatomist,

2 Churchill Street, Stockport Road, Manchester. (2) *Prepare rabbit bones as directed on pp.* 18 *and* 19.

2. **Models.**—Excellent models of brain, eye, skin section, &c., are made by many firms on the Continent. It is best to buy these *direct*, and Dr. Fritsch, Wladislawsgasse, Prague, can be thoroughly recommended. Catalogue will be sent post free on application.

III. DISSECTION.

1. **Instruments, &c.**—The minimum required is—a large scalpel, a small scalpel, a pair of large forceps, a pair of small forceps, bone forceps, a pair of small scissors, a pair of large scissors, a seeker, a razor, a German-silver blowpipe, and two mounted needles. These can be bought separately, and kept rolled up in a piece of wash-leather or in an American leather case. All of them, with two razors and two scalpels in addition, can be obtained in box for 25*s.* from C. Baker, 244 High Holborn. Good work can be done with penknife, ordinary scissors, and mounted bodkin (as seeker), but there are no substitutes for forceps and bone forceps.

A watchmaker's eye-glass is most useful in dissecting small structures, and a threefold lens for examination of villi, kidney, &c.

Frogs and parts of larger animals are best dissected under water in a pie-dish. They should be pinned on a piece of cork or soft board, weighted with sheet-lead. Pins should always be pushed in obliquely.

Drawing appliances are indispensable, and it is advantageous to indicate different structures by different colours, using pencils with coloured leads (*not* crayons). Vessels—containing pure blood, red,—containing impure blood, blue; nerves, green; liver, brown; and so on. Letter everything.

2. **Dissection.**—(1) Dissect *along* blood-vessels and nerves, and avoid seizing them with forceps. (2) Remember dissection largely consists in removal of connective tissue. (3) Keep dissection clean by sponge and

tap. (4) When large blood-vessels have to be cut, make two ligatures near together, and cut between. Ligature by tying a thread round and pulling tight, but don't overdo this. (5) *Draw* everything Attention is thus compelled and memory aided. (6) For classwork rough *home-made* diagrams, on large scale, and blackboard drawings in white and coloured chalks are most useful.[1]

3. Directions for Dissecting a Rabbit, to Illustrate General Arrangement and Structure of Organs.—The best way of killing a rabbit is to place it in as small a box as will conveniently hold it, having previously placed on the floor of the box a small piece of sponge or cotton-wool, saturated with a teaspoonful of chloroform. The box should be as nearly air-tight as possible.

N.B. is used to call attention to points where the rabbit differs markedly in structure from man.

(1) *Lay the animal on its back, on a board or deal table, fully extend its limbs, and fix them by means of nails through the paws.* Feel sternum and ribs through skin, and thus recognize positions of thorax and relatively large abdomen.

(2) *With the large scalpel make a longitudinal median cut through the skin of the thorax, continuing it forwards to chin and backwards to end of abdomen. A convenient plan is to push the handle of a scalpel under skin, through first incision, and then to cut down upon it, continuing same process in both directions. Separate the skin from underlying structures by means of scalpel, and pin down the flap on each side.*

NOTE.—(3) The **muscles of the neck** and a large, dark **jugular vein** on each side. (4) Powerful **muscles** covering the wall of the **thorax**, and largely concealing the **ribs** and **sternum**. (5) The soft, **muscular walls** of the **abdomen**.

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[1] Excellent diagrams are made to order by H. W. Gilbert Williams, 5 Canterbury Road, Croydon.

ABDOMEN.

(6) *With the large forceps pinch up part of the abdominal wall near the middle line. With the scissors, held horizontally, cut through the pinched-up part. Prolong with the scissors the oval aperture thus made to sternum in front, and to end of abdomen behind. Make transverse cuts in front, and pin back flaps.* The intestines of the rabbit are relatively much larger than those of man, and the position of parts as now seen is not exactly the same in every case. NOTE.—*Disturbing the position of the organs when necessary, but not tearing or cutting anything.* (7) The large, brownish-red **liver** in front, largely overlapping. (8) The bluish-white **stomach**. (9) The narrow, pinkish, much-convoluted **small intestine**. (10) **N.B.**—The large, greenish **cæcum**, marked externally by a spiral groove, and continued into a pale, finger-like **vermiform appendix**. (11) The much narrower, greenish **colon**, with pouched walls. (12) The pale, narrow, thick-walled **rectum**, usually containing balls of fæces. (13) The membranous folds of **mesentery** by which the various organs are suspended, continuous with (14) the **peritoneum**, a moist, shining membrane lining the abdominal cavity. (15) **Veins** and **arteries** in the mesentery. Each vein is generally accompanied by an artery, the former being full of blood and relatively large, the latter small, pale, and empty. (16) *Pull back the liver.* NOTE.—(17) The **diaphragm**, with muscular margins and translucent tendinous centre. Two masses of muscle, the **pillars of the diaphragm,** run back from its dorsal part to the ventral side of the backbone. (18) The pink **lungs** seen through the centre of the diaphragm. (19) *Perforate one side of the diaphragm with a scalpel,* and the corresponding lung will be seen to shrink away.

(20) *Turn the intestines over to the right side.* N.B.—Right and left are used in the sense of *the animal's* right and left. NOTE.—(21) The red, tongue-like **spleen** attached to the cardiac end of the stomach. (22) The **left kidney**, attached to the dorsal wall of the abdomen

a little way behind the liver. (23) The **left ureter**, a small, pale tube, running from the hilus of the kidney to (24) the pear-shaped **urinary bladder**, which can easily be made out in the posterior part of the abdomen. (25) The large, dark **inferior vena cava**, running in the middle line along the ventral side of the backbone. Trace it back, and notice that it is formed by union of large veins from legs and other parts. (26) The **aorta**, a bluish vessel, much smaller than the preceding, and running alongside it. Branches are seen running from it into the mesentery, and posteriorly it forks into the main arteries for the legs.

(27) *Turn the intestines over to the left side* and make out the **right kidney** and **right ureter**.

(28) *Turn the liver forwards.* NOTE.—(29) The greenish-black, pear-shaped **gall-bladder** imbedded in a slit in its right half. (30) The **portal vein**, branching in front into the liver and traceable behind into the veins which run in the mesentery.

THORAX.

(31) *Cut away with scissors the middle part of the sternum and enough of the ribs to expose the thoracic cavity, leaving the diaphragm uninjured, and not going to extreme front for fear of injuring the large vessels.* NOTE, disturbing the parts when necessary, (32) The pink, shrunken **lungs**, divided into lobes. (33) The **heart** enclosed in the **pericardium**. (34) The **thymus gland**, a pinkish fatty-looking mass at the base of the heart. (35) The **great blood-vessels** connected with the base of the heart. (36) The dark **inferior vena cava** piercing the diaphragm and running up to the heart. (37) The thick-walled **gullet** running through the thorax, dorsal to the preceding, and piercing the diaphragm to enter the stomach. (38) The **aorta** running from heart along ventral side of backbone and piercing diaphragm. (39) Two slender white cords, the **phrenic nerves**, traversing the thorax to branch up in the diaphragm. (40) Two similar cords, the **vagus nerves**, one running along the left side of the gullet and the other near its right side. (41) A pale, very slender

sympathetic cord running along each side of the backbone, just where the ribs begin, and swelling into a **sympathetic ganglion** on the head of each rib. (42) The outer layers of the **right** and **left pleuræ** lining their respective halves of the thorax (as the peritoneum does the abdomen), and meeting to form a median partition, except where separated by the heart. Note that the pleuræ resemble the peritoneum in texture and are reflected on to the lungs to form an inner layer, just as it is reflected on to the digestive organs.

NECK.

(43) *Carefully divide the muscles of the neck by a longitudinal median cut, and separate from structures which lie deeper. Avoid injuring jugulars.* NOTE. — (44) The **trachea** in the middle line, and hoops of cartilage which strengthen its walls. Trace it forwards and observe that it expands into the **larynx** at front end of neck. (45) A firm, narrow, pinkish **common carotid artery** running along each side of trachea. (46) A slender white cord, the **vagus nerve**, running close to the outer side of each common carotid. Traced forwards it swells into a ganglion, the **vagus ganglion**, a little behind the angle of the jaw. (47) *Pull one common carotid gently up with forceps.* This will put on the stretch a membrane connecting the artery with other structures. Running along in the membrane note the pale **sympathetic cord**. It is not unlikely to be confounded with other structures, but may be recognized with certainty by the fact that it swells in front into a **sympathetic ganglion** (superior cervical g.) close to the vagus ganglion, and into a similar sympathetic ganglion (posterior cervical g.) at the root of the neck.

DIGESTIVE ORGANS.

(48) *Skin the left side of the head, cutting off left ear.* NOTE.—(49) The **left parotid gland**, a soft lobulated mass in front of and below the ear. (50) The two ovoid pinkish **submaxillary glands**, lying between the two

halves of the lower jaw, and seen by turning the head back to its first position.

(51) *Remove the muscles from the left side of the lower jaw, and carefully break it away so as to expose the mouth-cavity.* NOTE.—(52) **N.B.**—The **teeth.** (53) The **tongue,** which differs in many points from human tongue, but **filiform papillæ** can be seen in its front part, and a couple of **circumvallate papillæ** on its upper side, very far back. Also note on its side the **left foliate papilla** (unrepresented in man), a small oblong area marked by numerous oblique ridges. (54) The **hard palate** in front of mouth-roof, followed behind by **soft palate. N.B.**—There is no uvula.

[With the aid of a looking-glass make out the characters of your own mouth-cavity. Note at back **soft palate, uvula,** and **opening into pharynx,** with **tonsil** on each side. Identify and count **teeth,** allowing for those lost or not yet cut. Note **papillæ** on tongue. *Put a few drops of vinegar upon it* and note that **fungiform papillæ** swell up. *Lift up tongue* and note ridge (p. 68) upon which the **submaxillary** and **sublingual ducts** open.]

(55) *Cut back laterally about an inch behind the tongue, along a paper roll pushed through the opening seen at the back of the mouth.* NOTE.—(56) The **pharynx,** a small chamber behind the mouth-cavity. On its floor, at the base of the tongue, note (57) an elastic flap, the **epiglottis.** (58) Behind this is a large aperture, the **glottis,** through which the handle of the seeker can be passed down into the trachea. (59) The beginning of the **gullet** just behind the glottis.

(60) *Pass a seeker forwards from pharynx above the soft palate and make a median incision through the latter.* The seeker will have been pushed through the **posterior nares** into a **posterior nasal chamber** which is now exposed. Note on its side wall (61) the small aperture of the **right Eustachian tube. N.B.**

(62) *Carefully separate trachea from deeper structures.* NOTE.—(63) The **gullet** running close to backbone. *Cut a slit in its wall and push knitting-needle upwards through it*

into pharynx. Trace gullet down through thorax. (64) *Carefully remove diaphragm and trace gullet into stomach.* (65) Compare the latter with fig. 38. (66) Very carefully identify and pull out the U-shaped loop of the **duodenum**. NOTE.—(67) The narrow but firm **bile-duct** running from liver into duodenum just beyond the pylorus. (68) **N.B.**—The **pancreas**, consisting of numerous fat-like lobules of pinkish colour, situated in the folds of mesentery enclosed by the U. (69) **N.B.** The short **pancreatic duct** opening into the side of the U further from stomach, about two inches beyond the bend.

(70) *Ligature the gullet and rectum. Cut through gullet above first ligature and through rectum below second. Remove stomach and intestines by cutting mesentery, leaving liver behind, and follow these parts out from end to end, preferably under water.*

(71) *Cut open and wash out stomach.* Note character of its walls and valvular constriction forming **pylorus.** (72) *Tear away mucous membrane from muscular layers.*

(73) *Remove a piece of small intestine. Cut open and pin out under water to show internal surface.* Note the velvety appearance of this, due to innumerable **villi**, which can be seen with the aid of lens.

CIRCULATORY ORGANS.

(74) *Cut through outer layer of pericardium.* Note escape of **pericardial fluid.**

(75) *Carefully tear away outer layer.* Note that at base of heart it is continued into an inner layer closely covering the heart.

(76) *Break away remains of sternum and anterior ribs. Remove thymus.* NOTE.—(77) The **jugular vein** on each side uniting with a **subclavian vein** from fore-limb to form **superior vena cava.** **N.B.**—Only *one* s.v.c. in man. (78) With the aid of figs. 57–59 recognize the auricles, ventricles, and pulmonary artery, tracing the last to the lungs. (79) *Turn the heart forwards* and (80) trace **aorta** to heart. Note (81) **pulmonary veins** running into left auricle

from lungs. (82) Trace **common carotids** to arch of aorta.

RESPIRATORY ORGANS.

(83) *Carefully remove trachea and lungs.* Note that trachea bifurcates into **bronchi**.

(84) *Tie a tube into trachea. Inflate the lungs by blowing. Cease blowing and they collapse.*

(85) *Cut through one bronchus, and with seeker and scissors follow it into substance of lung.* Note that it branches, and that the branches get smaller and more delicate.

(86) Examine a piece of the thoracic wall for the **intercostal muscles**.

MUSCLES AND JOINTS.

(87) *Skin one of the fore-limbs.* Note the numerous **muscles** and the **tendons** connected with them. (88) *Carefully remove the muscles* and examine **shoulder** and **elbow-joints**. (89) *Separate out the humerus.* Note the bluish layer of **cartilage** covering each end. (90) Use the humerus for studying the characters of fresh bone (cp. p. 18).

NERVOUS SYSTEM.

(91) *Place the animal on its ventral surface, and clean the skin and muscles from the skull and part of backbone. Starting from junction of the two break away the roof of skull and dorsal parts of vertebræ, by means of bone forceps, the blades of which must be kept horizontal.* The brain (**N.B.**) and part of spinal cord will thus be exposed and the **dura mater** and **pia mater** (p. 128) seen. Note in the **brain** (92) the two smooth **cerebral hemispheres**, broadest behind; (93) the narrow club-shaped **olfactory lobes** in front of these; (94) behind the hemispheres, a convoluted mass, the **cerebellum**, which rests on (95) the **bulb** (medulla oblongata) which is continuous with the **spinal cord**.

(96) *On the first day of dissection remove the brain and a piece of spinal cord as follows:—Break away side walls of skull and lift up brain in front with handle of scalpel. Work*

very carefully backwards, cutting through the roots of the cranial and spinal nerves as they appear. Place the brain and piece of cord on a piece of cotton-wool in strong spirit to harden for a few days. In brain, then, (97) *press hemispheres apart* and note the band-like **corpus callosum** connecting them. (98) *Bend the brain* so as to separate hemispheres and cerebellum, and note the **optic lobes** as four small elevations. (99) *Remove horizontal slices from hemispheres,* and note (100) the distinction between **grey** and **white matter**, and (101) the **lateral ventricles.** (102) *Slice the cerebellum,* and note the **arbor vitæ** appearance (p. 137). (103) *Remove the remains of the hemispheres and cerebellum.* Note the **axis of the brain,** which substantially resembles that of the human brain. The differences between the two brains chiefly lie in the cerebral hemispheres.

(104) Note the **spinal nerves** in the axilla (arm-pit), and *trace them into the fore-limb.*

SENSE ORGANS (Fresh Rabbit required).

(105) NOSE. *Break open one nasal cavity,* and note the (**N.B.**) **turbinated bones** covered by mucous membrane. (106) *Pass a seeker back into posterior nasal chamber, exposed as directed in* (51), (55), and (60).

(107) EYE. Note upper, lower, and third **eyelids,** the last folded up in anterior corner of eye. *Seize with forceps and draw over eye.* In man the 3rd eyelid is represented by the little red fold in the inner corner of the eye. (108) *Cut and break away roof of orbit,* and note (109) the four converging **rectus muscles.** (110) The **superior oblique muscle** (cp. p. 167). (111) *Lift up eyeball,* and note **inferior oblique muscle.** (112) *Clear away muscles,* and note **optic nerve** running into back of eyeball.

(113) EAR. *Skin left side of head, cut away left pinna, and follow external auditory meatus into head, cutting or breaking away surrounding structures.* At end of meatus note (114) the **tympanic membrane.** (115) *Cut this through,* and note (116) **tympanic cavity** and **auditory ossicles.**

IV. DIGESTION.

The chemicals mentioned, and preparations by Burroughs, Wellcome & Co., can be obtained from any chemist.

1. Properties of Starch, Sugar, and Proteids.

A. **Starch.**—Rub up a small quantity of powdered starch with a little water. Thoroughly mix with about 200 times its volume of water, and boil for five minutes. (*a*) Place a little of the starch mucilage thus obtained in a test-tube. Add a few drops of iodine solution. It *becomes blue.* (*b*) Touch your cuff with a drop of iodine solution. It *becomes blue*, showing presence of starch. (*c*) Put some starch mucilage in a dialyzer [1] (fig. 50), and immerse in distilled water. After some time test the water with iodine solution for starch. *No result.* The mucilage has not diffused through the membrane.

B. **Sugar.**—Use *maltose* (malt-sugar) or *glucose* (grape-sugar). Dissolve a little in distilled water. (*a*) Put a small quantity of this into a test-tube. Add four times the volume of Fehling's solution, prepared *at the time* from the Fehling test tabloids of Burroughs, Wellcome & Co. Boil. Note the *yellow* or *yellowish-red precipitate*, showing the presence of sugar.

(*b*) Place some sugar solution in a dialyzer, and after some time sugar will be found in the surrounding water by Fehling's test. Sugar, therefore, *diffuses.*

C. **Proteids.**—Break the *white* of a fresh egg into a cup and beat it well up. Shake well with 30 times its volume of distilled water. Filter through flannel. (*a*) Put some of the solution in a test-tube, and add a little strong nitric acid. *A white precipitate.* Boil. *It turns yellow, and partly dissolves to form yellow solution.* Let cool, and add some strong ammonia. The *colour changes to orange* (xanthoproteic reaction). (*b*) To a small quantity of the solution add four times its volume of acetic acid, and a few drops of strong solution of potassium ferrocyanide. *A precipitate.* (*c*) Boil some of the solution. *It coagulates.* (*d*) Place some of the solution in a dialyzer, and after some time has elapsed test the surrounding water for proteid by (*a*) and (*c*). *No result.* Proteids do *not diffuse.*

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[1] The prepared skins used in making sausages answer the purpose well, after soaking in water. See that no visible holes are present.

2. Saliva. Gastric Juice. Pancreatic Juice.

In all cases where the digestive action of these juices is to be experimented on, stand the vessels containing the solutions in water as hot as the hand can bear easily.

A. **Saliva.**—Wash out the mouth, and stimulate the secretion of saliva by chewing a small piece of india-rubber. Collect, filter, and dilute with five times its volume of distilled water. (*a*) Put a little starch-mucilage in a test-tube. Add $\frac{1}{3}$ the volume of saliva. Leave for an hour, and then apply Fehling's test. *Sugar will be found.* Use same test with starch-mucilage alone, and saliva alone. *No result.* (*b*) Put some starch-mucilage mixed with saliva in a dialyzer, and leave for some hours. Take some of surrounding water and apply Fehling's test. *Sugar will be found.* (*c*) Boil some saliva, and add it to starch-mucilage. After some time apply Fehling's test. *No result.* The ptyalin has been destroyed.

B. **Gastric Juice.**—Use the pepsin preparations of Burroughs, Wellcome & Co. *i.e.* "Pepsin in Scales" or else "Glycerinum Pepticum", adding as well some 0·2 per cent. hydrochloric acid. It is also instructive to prepare peptic glycerine from the rabbit's stomach. Open quickly, wash, scrape away the mucous membrane in shreds, place the scrapings in strong glycerine for eight days, pour off. Use in same way as other preparations. (*a*) Add a little pepsin to some white-of-egg solution or blood-fibrin. Put in a dialyzer and leave for some hours. (*b*) Apply xanthoproteic test to part of surrounding water. *Result as in* 1, C, (*a*). (*c*) Boil another part. *No result.* (*d*) Test another part with acetic acid and potassium ferrocyanide. *No result.* **Peptone**, differing in many ways from proteid, *has been formed, and has diffused through the membrane.* (*e*) Repeat the foregoing experiments, having previously boiled the pepsin in a little water. *No result.* The ferment has been destroyed.

C. **Pancreatic Juice.**—Use the Zymine Peptonizing Powders of Burroughs, Wellcome & Co., and by employing method described, except that no acid is added, prove that it can digest starch and proteid. Boiling, as before, destroys the ferments. Glycerine pancreatic extract may be prepared by mincing the pancreas of a pig and treating as in IV., 2, B.

3. Emulsification of Fat.

Into a watch-glass pour some ¼ per cent solution of sodium carbonate. With a glass rod place a drop of *rancid* oil in the solution. Note that the drop gradually gets milky, and the watch-glass will in the end be found full of white fluid, which is an emulsion of fat. Examine under the microscope, and note the minute fat globules.

4. Digestion of Milk.

1. Take two specimens, and treat one with pepsin preparation and hydrochloric acid, the other with peptonizing powder, according to method previously described. In either case note (1) *curdling*, from action of a special ferment; (2) *dissolving of the curds with formation of peptone.*

2. Procure some **rennet**, which is an extract from the stomach of the calf, and contains rennin. (1) Add a few drops to some warm milk, and note *the curdling.* (2) Add some rennet to boiling milk. *No result.* The rennin is destroyed by the heat.

V. THE HEART.

1. **Structure of the Sheep's Heart** (cp. figs. 57–60).—Procure a sheep's "pluck", *i.e.* heart and lungs. (1) *Dissect away pericardium,* and recognize **auricles** with their **appendages**, **ventricles**, **pulmonary artery**, and

coronary vessels branching on the surface of the heart. The front (ventral) side can be distinguished by a furrow filled with fat, running along boundary between ventricles. Left side can be distinguished by the firmer feel of left ventricle, which alone extends to apex.

(2) *Trace pulmonary artery to lungs, and pulmonary veins from them. Carefully cut lungs away.* Note—(3) **Superior vena cava.** (4) **Inferior vena cava.** (5) **Coronary sinus**, opening close to (4).

(6) *Ligature* (4) and (5). *Tie a short glass tube into* (3), *and a larger one into pulmonary artery. Pour water into the short tube and squeeze R. ventricle.* Note that water ascends in long tube, but does not run back, owing to closure of **pulmonary semilunar valves.**

(7) *Open right auricle by cutting along the superior and inferior venæ cavæ.* Note.—(8) The **Eustachian valve**, a fold guarding the opening of the I.V.C. (9) The **Thebesian valve**, a similar fold guarding the opening of the coronary sinus. (10) The **auricular septum.** (11) The large **right auriculo-ventricular opening.**

(12) *Cut open the left auricle.* Note—(13) The openings of the 2 (**N.B.**) **pulmonary veins.** (14) The **auricular septum.** (15) The large **left auriculo-ventricular opening.**

(16) *Pour water through the auricles into the ventricles.* Note that the flaps of the auriculo-ventricular valves float up.

(17) Cut across the ventricles, a short distance from apex of heart. Notice the **relative shape** of the ventricular cavities, and the **relative thickness** of the ventricular walls.

(18) *Cut away outer wall of right ventricle.* Note—(19) **Tricuspid valve.** (20) **Papillary muscles** and other columnæ carneæ. (21) **Chordæ tendineæ.** (22) *Pass a seeker up into pulmonary artery.* (23) *Cut pulmonary artery short.* Note **pulmonary semilunar valves.** (24) *Slit up pulmonary artery*, and examine valves more closely.

(25) *Cut away outer wall of left ventricle* and note **mitral valve, aortic semilunar valves**, &c., as above. (26) Note, in the opened aorta, two small holes just

behind two of the semilunar valves. These lead into the **coronary arteries.**

The preceding directions will serve for the dissection of the rabbit's heart, if for "coronary sinus" "left superior vena cava" is substituted.

2. **Movements of the Heart.**—(1) When a just-killed rabbit is opened the heart will probably be seen beating, and the **alternate contraction of auricles and ventricles** can be noticed. (2) *Chloroform and open a frog in same way as described for rabbit.* (N.B. There is no diaphragm, and the structure differs in many other ways from that of rabbit.) Note the **heart** in its **pericardium.** It **beats regularly,** and will continue to do so for some time, even if removed from the body. *Dissect away the pericardium,* and note that the two dark thin-walled **auricles** and the firm paler **ventricle undergo systole alternately.**

3. **Cardiac Impulse and Pulse.**—(1) *With the right forefinger find the place between your left fifth and sixth ribs, where the cardiac impulse is best felt.* (2) *With the left forefinger feel the 'pulse' in the right wrist* (ventral surface, thumb side). Note the rhythmic swelling of the artery which takes place. It can be seen with the eye. (3) *Place the right forefinger as in* (1), *and, at the same time, the left forefinger as in* (2). Note the time-relation betweeen the pulse in the wrist and the cardiac impulse.

VI. Coagulation of Blood.

(1) *Let some of the blood from a freshly killed rat or rabbit run into a small beaker.* Note the stages of coagulation (cp. p. 83). (2) *Prick your finger with a needle, and transfer a drop of blood to a glass slide.* Note that it soon passes into the jelly stage. (3) *Rapidly stir with a feather some freshly shed blood.* Note that threads of fibrin collect on the feather, and that the remaining part of blood (corpuscles and serum) remains liquid.

VII. CIRCULATION OF BLOOD IN WEB OF FROG'S FOOT.

Cut out a small V-shaped piece from one end of a flat piece of wood, such as the lid of a cigar box. Make a small calico bag just large enough to hold a frog. Put a frog in it, except one leg, and firmly tie to board by means of tape. Gently extend the leg, and fix the foot over the V slit by means of pieces of thread tied to the toes at one end, and at the other wound round pins stuck in the board. Examine the web under the microscope, supporting the board by books, &c. Note the circulation in the web (p. 98), which should be gently on the stretch, and kept damp with normal salt solution (¾ per cent). The frog-bag should be kept wet with water.

VIII. RESPIRATION.

1. **Movements of the Thoracic Walls.**—(1) *Open the abdomen of a recently killed rabbit so as to expose the diaphragm. Lay bare the trachea, tie a tube into it, and fully inflate the lungs.* Note meanwhile the movements of the sternum, ribs, and diaphragm. *Cease blowing*, and note the contrary movements. (2) Note the movements of your own thorax during respiration. (3) *Construct the model represented in fig.* 12, and satisfy yourself by means of it as to the action of the intercostal muscles.

2. **Differences between Inspired and Expired Air.**—(1) *Breathe on a mirror or polished metal surface.* Note the film of moisture. (2) *Prove the presence of* carbon dioxide *in expired air.* Cp. p. 110. (3) *Pour a little strong sulphuric acid on some form of* organic matter, *e.g. a piece of white paper.* Note the blackening that occurs. (4) *Breathe through a fairly long glass tube into a small quantity of strong sulphuric acid placed in a beaker.* Note the blackening which takes place, owing to the presence of organic matter.

IX.—NITROGENOUS EXCRETION.

1. **Structure of Sheep's Kidney.**—(1) *Remove fat, &c.* Note **hilus** and **ureter**. (2) *Cut it through parallel*

to flatter sides (cp. fig. 72). Note dark-red **cortex**, striated **medulla**, **urinary pyramids**, **urinary papillæ**, **pelvis**. (3) *Examine cortex with lens.* Note the numerous red dots. These are **Malpighian bodies**. (4) *Examine with lens uncut part of a urinary papilla.* Note minute **openings** of **uriniferous tubules**. *Squeeze*, and note escape of drops of **urine**.

2. **Urea.**—As obtainable from chemist. (1) Note the slender needle-like crystals. (2) *Heat a small quantity in a test-tube.* Note that it first melts and then gives off ammonia, recognizable by its smell.

X.—Muscle and Nerve.

1. **To Pith a Frog.**—*Place it under a tumbler with a piece of cotton-wool soaked in ether. As soon as it becomes insensible take it out, and holding it in a cloth in the left hand, bend down its head with the left forefinger. With the point of a scalpel make a fairly deep, but narrow, transverse cut through skin and muscles at back of skull thus indicated. Push a blunt needle forwards through foramen magnum* (here situated at *back* of skull) *and move it about so as to destroy brain.* The same end may be attained by decapitating a frog with stout scissors, leaving lower jaw uninjured.

N.B.—The preceding should not be done in the presence of an elementary class.

2. **Reflex Action.**—(1) Take a pithed or decapitated frog, and note the lifeless attitude assumed (p. 140). (2) *Pass a bent-pin through lower jaw and hang up to retort stand or other support.* Note position. (3) *Pinch one toe with forceps.* The leg is drawn up. (4) *Place a small piece of blotting-paper soaked in acid on the skin of the back.* Note the reflex movements directed to removal of the blotting-paper. (5) *Destroy the spinal cord by pushing a wire down neural canal.* Reflex actions can no longer be set up.

3. **Direct Stimulation of Motor Nerves.**—(1) *Lay the frog on its back. Open it and turn viscera aside.* Note the **posterior spinal nerves** as white cords running along the back of the body. *Pinch them with forceps.*

Note movements produced. (2) *Lay the frog on its front. Skin one thigh. Carefully separate muscles.* Note the large **sciatic nerve** of the leg running close to the femur. *Carefully dissect away muscles of the thigh, taking care not to injure the nerve. Cut through nerve as near body as possible.* Note movement which follows. *Dissect out nerve without dragging or touching it, by clearing away surrounding connective tissue. Cut across femur and fix its cut end in a letter clip* (such as may be had for 1d.). *Fix clip so that leg is horizontal and nerve hangs down. Pin a stiff slip of paper to foot.* (3) *Pinch end of nerve.* Note movement. (4) *Cut off pinched part of nerve and let the end dip into a watch-glass containing saturated salt solution.* Note movements gradually set up. (5) *Remove salt solution, and cut away nerve.* Note result. (6) *Make a muscle-nerve preparation* (cp. p. 133 and fig. 78). *Fix stump of femur in clip, and pass one of the smallest sized fish-hooks through the lower tendon. Load the gut of the hook with one or two small split shot.* Stimulate the nerve as in 3, (3) and (4). Note twitching of the muscle which results. These may be made more obvious by fixing a straw fibre to the gut in a horizontal position. The muscle-nerve preparation must be kept damp by normal salt solution applied with a camel-hair brush.

XI.—Touch.

1. **Acuteness of the Sense of Contact.**—*With a pair of blunted compasses, the ends of which have been varnished, and a good scale of inches and fractions test the relative sensitiveness* (p. 147) *to contact of different parts.*

2. **Temperature Sense.**—(1) *Procure a small copper rod about six inches long, and sharpen it at one end to a blunt point. Dip in hot water and gently apply the point here and there to back of wrist and other parts of body.* Note that at certain "hot spots" the sensation of warmth is much keener than elsewhere. (2) *Determine in similar way* that "cold spots" exist.

XII.—TASTE.

1. *Prepare solutions of quinine* (strong), *sugar* (5 per cent), *common salt* (10 per cent), *and acetic acid* (1 per cent), *and by means of small camel-hair brushes apply them successively to different parts of the tongue.* Note differences in sensations experienced (p. 149).

2. *Perform experiment with sugar-crystal described on p.* 149.

XIII.—SMELL.

Eat a piece of onion, holding the nose at the same time. Note its comparative "tastelessness" under these conditions (p. 149).

XIV.—HEARING.

Try the tuning-fork experiment described on p. 156.

XV.—SIGHT.

1. **Dissection of Sheep or Bullock's Eye** (under water).—(1) *Remove muscle, fat, &c.* Note **optic nerve, sclerotic, cornea, iris, pupil.** (2) *Remove cornea.* Note escape of **aqueous humour.** Examine iris. (3) *With the handle of a scalpel gently separate sclerotic from underlying structures for half an inch all round. Cut away the part so separated.* Note the **ciliary muscle** as a pale band at the outer margin of the iris. (4) *With a sharp razor divide the eye into front and back halves.* (5) Note escape of jelly-like **vitreous humour,** surrounded by **hyaloid membrane.** (6) In back half (cp. fig. 94) note **blind spot** and **yellow spot.** (7) *Peel away retina,* which will be seen as a delicate soft membrane. Note that it adheres closely at blind spot. (8) Note pigmented **choroid** thus exposed. *Peel it away,* and note **sclerotic.** (9) In front half (cp. fig. 93) note **ciliary processes** and **lens** in its **capsule.** (10) *Remove lens,* and note its **elasticity.** (11) *Peel away coats* as before.

2. **Formation of Image.**—*Remove sclerotic from part of the back of a fresh eye. Fix eye in a tube of black paper, and direct cornea to window.* Note inverted picture of external objects seen on back of eye.

3. **Accommodation.**—(1) *Try candle-flame image experiment* (p. 165) on another person. Note that when a near object is looked at the second image alters its shape and the pupil gets smaller. (2) *Hold up one finger a little way in front of your face.* Note that you cannot see both it and distant objects clearly at the same time. Note also the sense of effort experienced as you look from distant objects to it.

4. **Blind Spot.**—*Try experiment given on p.* 167, *with pairs of marks of different sizes, shapes, and distances apart.*

5. **Narrowing of Iris in Near Vision.**—*Hold up a pin before the face and look at it with one eye.* Note that when held very near its image is *blurred. Prick a pin-hole in a piece of card and look at pin through it.* Note that it can be held much nearer than before *without blurring* of image (cp. p. 66).

XVI.—HISTOLOGY.

1. **Use of Compound Microscope.**—(Fig. 100.) Consists of a **stand** supporting a tubular **body** into the ends of which lenses are fitted. The upper lenses are contained in a movable **eye-piece**, the lower ones in an **objective**, which screws on and off. The object to be examined is placed on a **glass slide** and generally covered with a very thin piece of glass, *i.e.* a **cover-slip**. The horizontal plate projecting from the stand is the **stage**, on which the slide is supported. It has a hole in its centre through which light can be directed by means of a **mirror** placed below it. The amount of light can be regulated by a **diaphragm**, revolving below the stage, and perforated by holes of different size. Eye-pieces and objectives are termed low or high according to the amount they magnify. The higher the eye-piece the

shorter it is and the smaller its upper lens. The higher the objective the smaller its lens. Adjustment to the right distance, or **focussing**, is effected (1) by twisting the tube up and down in its sheath. This is the **coarse adjustment**; (2) by means of the **fine adjustment**, worked by a screw at the top of the stand. The following points are of great importance:—(1) Keep the lenses clean by means of a piece of wash-leather or old silk handkerchief. (2) Use low power first. (3) Use a **small** hole of diaphragm when working with **high** power. (4) *Focus* by twisting tube down till objective is close to cover-glass, then look through eye-piece and slowly twist up tube till object is seen. Lastly, use fine adjustment.

The microscope recommended is Leitz's small one, represented in fig. 100, and supplied for £3, 12s. 6d., carriage paid, by Mr. Chas. Baker, 244 High Holborn. It possesses high and low eye-pieces, high and low objectives, and is contained in a mahogany box.

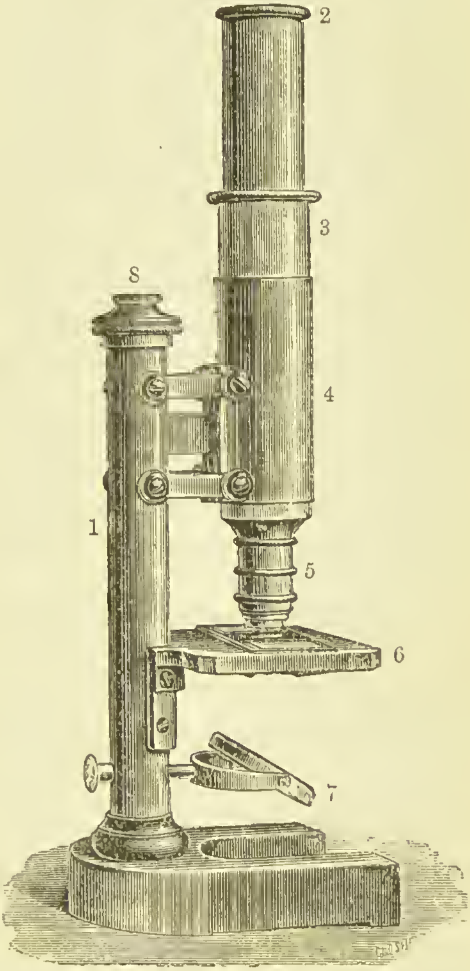

Fig. 100.—Leitz's Student's Microscope.

1, Stand; 2, eye-piece; 3, body; 4, body-tube; 5, objective; 6, stage; 7, mirror; 8, fine adjustment.

2. **Reagents.**—The ones required for the purposes of this book are as follows. They are best kept in 1 oz. bottles, provided with corks in which pieces of glass rod

are fixed. (1) **Normal** (*i.e.* $\frac{3}{4}$ per cent) **solution of common salt.** Fresh tissues are to be examined in this. (2) **Weak glycerine,** *i.e.* half glycerine, half water. Tissues that have been preserved in alcohol, &c., are to be examined in this. (3) **Acetic acid** (1 per cent). Dissolves granules and brings nucleus into view. (4) **Eosin solution** (5 per cent). Can be replaced by red ink. Stains different parts to different extent and helps to bring very transparent structures into view.

3. **Blood.**—(1) *Prick your finger and place a drop of blood on a slide. Put on a cover-glass by resting one edge on slide and gently lowering with needle.* Under microscope note (2) the enormous number of **red corpuscles**, the shape of which may be made out as they roll over, (3) a much smaller number of rather larger **white corpuscles**, seen as rounded bodies. (4) As the blood coagulates note that the red corpuscles adhere together in rolls (fig. 54). (5) *Mount a very small quantity of blood in a mixture of acetic acid and eosin.* Note a deeply-stained particle, the **nucleus**, in each white corpuscle. Nothing of the kind can be seen in the red corpuscles.

4. **Epithelium.**—A, Squamous. (1) *Scrape the inside of the cheek with the handle of a scalpel.* Mount some of the scrapings in normal salt solution. Note the flat nucleated cells (fig. 45). (2) *Run in a little acetic acid by placing a drop of it on one side of the cover-glass and a fragment of blotting-paper on the other.* The nucleus becomes more distinct. (3) *Run in a drop of eosin, and after two minutes follow by glycerine.* Cells have stained, the nuclei most intensely. (4) *Examine prepared specimen of cast skin of frog or newt.* Note nucleated cells united by their edges. (5) *Examine prepared section of skin.* Note that the epidermis consists of numerous layers of cells (fig. 83). B, Columnar. (1) *Gently scrape with a scalpel the inner surface of a piece of rabbit's small intestine which has been cut open and pinned out in 30 per cent alcohol for 24 hours. Tease out* (*i.e.* tear up with mounted needles) *on slide in drop of glycerine. Cover and examine.* Note cells (fig. 42). (2) *Run in eosin and follow up with more glycerine.* Note

staining, especially of nuclei. (3) *Examine prepared section of small intestine.* Note **villi** covered by layer of **columnar epithelium.** C, Ciliated. (1) *Scrape roof of mouth of freshly-killed frog. Gently tease up in drop of normal salt solution.* Note in clumps and isolated the broad **ciliated cells** with active cilia. (2) *Treat as in* A, (3). (3) *Slit open trachea of just-killed rabbit. Gently scrape interior and tease scrapings in normal salt solution.* Note **columnar ciliated cells** (fig. 67). (4) *Treat as in* A, (3). D, Glandular. (1) *Scrape the surface of liver of just-killed frog or rabbit. Tease in normal salt solution.* Note the nucleated **liver-cells** with squarish or polygonal outlines (fig. 49). (2) *Examine prepared section through cardiac end of stomach.* Note **gastric glands** (p. 43). (3) *Examine prepared section of pancreas.* Note the **tubules** cut across in various directions and presenting circular, oval, &c., outlines. Note the **large nucleated cells** with squarish outlines, by which tubules are lined. E, Sensory. (1) *Examine prepared section of retina.* Note **rods and cones** (fig. 95).

Good prepared slides at a reasonable price can be obtained from H. Meller, anatomist, 2 Churchill Street, Stockport Road, Manchester.

CHAPTER XII.

DIGESTION IN THE OX AND COW—SECRETION OF MILK.

The main principles of digestion and the processes by which it is succeeded are the same for an ox or cow as for a man, and these principles have already been explained at some length in the preceding part of the book. The food of an ox contains, as before, nitrogenous substances (proteids), and non-nitrogenous substances (carbohydrates, fats, salts, and water), which are subjected to mechanical and chemical action within the alimentary canal, and thereby reduced to a fit state for absorption into the blood-vessels and lacteals,—in other words are *digested.* The difference between man and the ox as regards digestion lies in this,—the former lives most conveniently on a mixed diet, while the latter is entirely herbivorous, and as a result the arrangement and structure of the digestive organs are by no means similar in the two cases.

DIGESTIVE ORGANS OF THE OX.

As in all animals which live exclusively on vegetable food the alimentary canal is extremely long, the intestine alone being some twenty times the length of the body. This results from the fact that vegetable food is very bulky, and takes a long time to digest, while at the same time a very large absorptive surface is required in order to ensure the extraction of all the digested matter. The regions of the digestive tube are,—mouth, pharynx, gullet, stomach, small intestine, and large intestine. Salivary glands, liver, and pancreas are present, as in man.

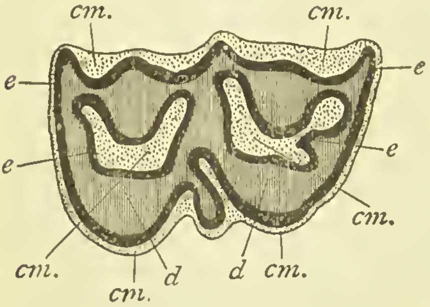

Fig. 101.—Crown of Grinder in Ox. [After Bos.]

cm, Cement (dotted); *d*, dentine (shaded with lines); *e*, enamel (represented black).

Mouth.—The **mouth opening** is situated at the end of a broad bare muzzle, and the upper lip is short. The **cavity of the mouth** is large, and much elongated from before backwards in accordance with the length of the jaws, which are comparatively weak. As compared with man the most striking differences are found in the tongue and teeth. The large **tongue** is pointed in shape, and its surface is rough owing to the presence of numerous backwardly directed sharp-pointed papillæ. As to the **teeth**, upper incisors and canines are entirely absent, their place being taken by a hard elastic pad against which the lower incisors and canines[1] bite. The back teeth possess flat-ridged crowns adapted for grinding. They are of the kind known as "composite", *i.e.* the enamel layer is folded into the tooth as represented in fig. 101, forming projecting ridges, the valleys between which are filled up with cement. The *dental formula* is

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[1] These canines are reckoned as the outermost incisors in most veterinary works.

$$i. = \frac{0-0}{3-3} \quad c. = \frac{0-0}{1-1} \quad p.m. = \frac{3-3}{3-3} \quad m. = \frac{3-3}{3-3} = 32.$$

Well-developed submaxillary, sublingual, and parotid salivary glands open into the mouth-cavity.

Pharynx and Gullet. — The mouth opens behind into a large pharynx, and this again is continued into a long gullet which traverses the neck and thorax, pierces the diaphragm, and is succeeded by the stomach.

The **Stomach** (fig. 102) is relatively of enormous size, being capable of holding some 55 gallons of food, and, as in all animals which *ruminate* or "chew the cud", is of very complex nature. It consists (see fig. 102) of four sub-divisions, as follows:—(1) the **paunch** (rumen), a large bag (*pa.*) with a capacity equal to $\frac{9}{10}$ that of the entire stomach. Its mucous membrane is raised into numerous papillæ, and it communicates by a large opening with

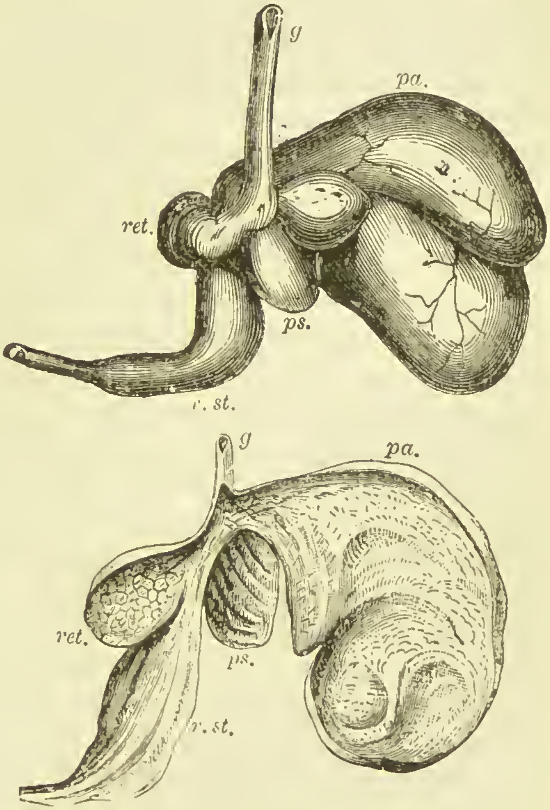

Fig. 102.—Stomach of Sheep. Exterior and Interior.
g, gullet.

(2) the **honey-comb bag** (reticulum), the smallest compartment (*ret.*), which receives its name from the fact that the mucous membrane which lines it is raised up into folds arranged like the cells of a honey-comb. A very small aperture connects the cavity of the reticulum with that of (3) the **manyplies** (psalter, omasum) (*ps.*), so named because its mucous membrane presents very numerous flattened folds, something like the leaves of a book. (4) The **rennet stomach** (reed, abomasum) (*r. st.*), lined by mucous membrane raised into folds which are transverse at the upper end and longitudinal in the middle.

The first three chambers may be regarded as the dilated lower end of the gullet, which they resemble in the fact that they are lined by stratified pavement epithelium. The superficial cells of this epithelium constitute a horny layer. The mucous membrane lining the last chamber resembles that of the human stomach, for it is covered by simple columnar epithelium, and numerous gastric glands are imbedded in it. Such glands are entirely absent from paunch, honey-comb bag, and manyplies.

Intestines.—The **small intestine** is a relatively narrow ($\frac{1}{2}$ to $\frac{3}{4}$ of an inch) much convoluted tube, about 150 feet long, following the rennet stomach, which communicates with it by a pyloric opening. Its mucous membrane is raised into innumerable villi. As in man the small intestine communicates by a valvular opening with the much wider **large intestine**, which is from 30 to 40 feet long, and is divided into cæcum, colon, and rectum, the first of which is from 2 to 3 feet in length. As might be anticipated, the intestines are packed into the abdominal cavity in a way differing in many details from that already described for man.

The **liver** is a large compact brown organ placed in the front part of the abdominal cavity and abutting upon the right half of the diaphragm.

A **gall-bladder** is present. The **bile-duct** opens into the duodenum 2 feet or more beyond the pylorus.

The **pancreas** is a broad flattened gland, situated in the loop of the duodenum and pouring its secretion into the small intestine by means of a **pancreatic duct**, opening about 15 inches beyond the bile-duct, and thus contrasting with the arrangement found in man (p. 70).

PROCESSES OF DIGESTION IN THE OX.

Reception of Food.—The rough, highly mobile tongue plays a very important part in grazing, seizing the herbage and drawing it into the mouth, where it is divided by the incisors and canines of the lower jaw, which bite against the hard pad that takes the place of upper incisors. The tongue also assists in drinking, acting as a kind of piston by which water is pumped into the mouth.

Digestion in the Mouth.—In all animals which, like the ox, "chew the cud" or ruminate, the food is chewed twice *i.e.* (1) when taken into the mouth from the exterior, and (2) when returned to the mouth as "cud" after having been macerated for some time in the paunch. The first chewing is very rapid, the grass, &c., being swallowed after it has been subjected to two or three strokes of the grinding-teeth. The second chewing, on the contrary ("chewing the cud"), is prolonged, and it has been estimated that during the 24 hours an ox spends, on the average, 3 hours in actual feeding and 5 in rumination. During the latter operation a characteristic attitude is assumed, the animal lying a little to one side with legs bent up under it. Two things connected with digestion in the mouth are specially noteworthy, (*a*) the action of teeth, (*b*) the action of the saliva. (*a*) **Action of the Teeth.**—The way in which the incisors are used has already been noticed. The grinders act like millstones, serving to crush and break down the food, while during this operation the tongue and cheeks help to mix up the food, so as to ensure thorough mastication. An efficient millstone is not of the same hardness throughout, but wears away unequally, and is consequently kept rough. A similar purpose is served by the presence of three distinct materials of different degrees of hardness in the grinding teeth of the ox, for these materials (enamel, dentine, cement, fig. 101) are ground down at different rates, and consequently the crowns of the teeth are kept irregular. During this process of chewing the jaws work from side to side, not in a perfectly symmetrical way, but in a one-sided manner, for a number of strokes are given, say, from left to right, after which the direction will be reversed, then follows a return to the first direction, then a reversal, and so on. The joints between the condyles of the lower jaw and the skull are comparatively loose in correspondence with the nature of these side-to-side movements. The condyles are convex from before backwards and slightly concave from side to side, and the surfaces against which they play are of corresponding shape.

(*b*) **Action of the Saliva.**—As in the case of man the secretion has both a mechanical and chemical action (p. 72), but it is here of greater physiological importance, for salivary digestion very largely takes place in the paunch and honey-comb bag as well as in the mouth. About a hundredweight of saliva is secreted during the 24 hours, something like $\frac{5}{7}$ of this enormous quantity being poured into the mouth while feeding and rumination are going on (8 hours). The reason for increased flow of saliva at these times is found in the fact that the secretion is stimulated by the presence of food in the mouth, and by the movements of the jaws.

Digestion in the Stomach.—The food, when first swallowed, passes for the most part into the paunch, but also, to some extent, into the honey-comb bag, which also has the special function of storing liquid. It then undergoes a slow process of churning to and fro between these two chambers of the stomach, and meanwhile the saliva, with which it is soaked, exerts a softening and dissolving action. The next process is the one so characteristic of ox, sheep, goat, and related animals,—*i.e.* **rumination**, or "chewing the cud", in which portions of the softened and partly-digested food are returned to the mouth, and there masticated more thoroughly, while, at the same time, the saliva continues to act upon them. This return of the food to the mouth is brought about as a result of reflex nervous action (p. 134) by contraction of the paunch and reticulum, diaphragm, and muscular walls of the abdomen. It can only take place when the stomach is distended by food, and may be compared to vomiting. The contraction of the parts named forces a rounded "bolus" of food into the lower end of the gullet, the muscular wall of which contracts so as to carry the bolus back into the mouth. This upward passage may readily be noted in an animal engaged in rumination during the pauses when the chewing action ceases. After the *second* prolonged chewing the food is once more swallowed, and those parts of it which are finely divided pass along a muscular œsophageal groove running from the lower end of the gullet to the manyplies, which acts as a kind of strainer preventing any but small particles from entering the fourth chamber or abomasum. It is only then that true gastric digestion by means of the **gastric juice** takes place, in the way described earlier (p. 74). There is nothing in human digestion to parallel the processes taking place in the paunch, reticulum, and manyplies, which are, as it were, extra parts of the digestive apparatus.

Digestion in the Intestines.—This resembles, in essential respects, the corresponding processes taking place in the human intestines (p. 75), the chief chemical agents being the **bile** and **pancreatic juice**.

ABSORPTION OF DIGESTED FOOD.

As a result of the mechanical and chemical agencies to which it is subjected in the mouth, gullet, stomach, and intestines, a considerable part of the food is either dissolved, as in the case of proteids, sugar, and starch, or reduced to a fine state of division, as is the case with fats. The final upshot is the same as in man, *i.e.* the digested proteids, sugar, and starch are absorbed into the capillaries of the alimentary canal, while the digested fats pass into the lacteals, and ultimately reach the blood system by way of the thoracic duct (see pp. 76–78).

FOOD.

In dealing with questions relating to the feeding of any particular farm animal, it must be remembered that a considerable part of the fodder is indigestible, and passes out of the body in the dung. If, for example, **meadow hay** is taken as the standard food for horned stock, the chemical analysis, regarded by itself, would be very misleading. It is necessary to supplement it by other figures giving the proportions of the *digestible* constituents, as in the following statement [1] regarding meadow hay of average quality:—

Chemical Composition.						Digestible Constituents.		
Water.	Ash.	Albuminoids.	Woody fibre.	Carbohydrates.	Fats.	Albuminoids.	Carbohydrates.	Fats.
14·3	6·2	9·7	26·3	41·4	2·5	5·4	40·7	1·0

It is found convenient to express the relation between the digestible constituents by what is known as the "**albuminoid ratio**", which is obtained as follows:—

$$\frac{\text{Carbohydrates} + (\text{Fats} \times 2\tfrac{1}{2})}{\text{Albuminoids}}$$

Thus, for average meadow hay, the ratio is—

$\frac{40{\cdot}7 + (1{\cdot}0 \times 2\frac{1}{2})}{5{\cdot}4} = \frac{43{\cdot}2}{5{\cdot}4} = 8$, or more fully expressed 1 : 8, where 1 stands for the digestible albuminoids taken as unity and 8 for the digestible carbohydrates and fats calculated with reference to this. For different animals, and for different aims the necessary albuminoid ratio differs, as appears from the following figures[1]:—

---

[1] Taken from Wolff.

Oxen taking no exercise, ...	1 : 12·0
,, ,, moderate exercise, ...	1 : 7·5
Fattening oxen, 1st period, ...	1 : 6·5
,, ,, 2nd ,, ...	1 : 5·5
,, ,, 3rd ,, ...	1 : 6·0
Milch Kine, ...	1 : 5·4

A ratio is *wide* (*e.g.* 1 : 12) when the proportion of albuminoids is small, *narrow* (*e.g.* 1 : 5·4) when it is large. Taking the last example for further consideration, it appears that the hay, of which the analysis is given above, does not contain a sufficient quantity of albuminoid matter to keep milch kine in a proper condition, and it would be necessary to supplement it with richer food, such as oil-cake. It has been shown by a large number of experiments that to maintain the ratio 1 : 5·4 in the feeding of milch kine, it is necessary to give the following daily amounts of albuminoids, &c., for every 1,000 lbs. live weight[1]:—

Total Organic Substance.	Digestible Matter.			
	Albuminoids.	Carbohydrates.	Fats.	Total.
lbs. 24·0	lbs. 2·5	lbs. 12·5	lbs. 0·40	lbs. 15·40

As might be expected these proportions are those actually found in good meadow grass, which is, therefore, a sufficient food in itself, but the same end may be gained by using various mixtures, which can be easily calculated when the kinds and quantities of the digestible components of the food-stuffs employed are known.

[1] Taken from Wolff.

MILK.

Physical and Chemical Characters.—Milk is an opaque opalescent liquid which, when seen in thin layers, is of a bluish colour. It has an alkaline reaction, is sweetish to the taste, and possesses a characteristic odour. When examined under the microscope (fig. 103) it is found to consist of innumerable **fat-globules** floating in a liquid **plasma**, and having an average diameter of $\frac{1}{5000}$ of an inch. Milk is, in fact, a natural emulsion (see p. 76), consisting as it does of finely-divided fat suspended in a liquid. A pint of milk contains more than 500,000 millions of such fat-globules. Placed in a row these would stretch about 8 miles.

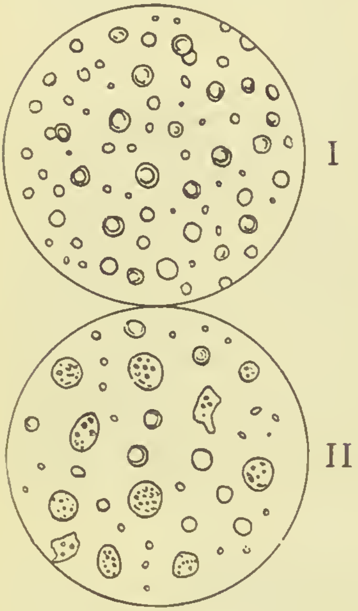

Fig. 103.—Milk (I), an colostrum (II), much magnified. The dotted bodies in II are colostrum corpuscles.

The average percentage chemical composition of milk is as follows:—

Water, ...		87·0
Solids, consisting of—		
1. Albuminoids (chiefly casein),	4·0	
2. Carbohydrates (milk-sugar),	4·6	
3. Fats, ...	3·7	
4. Inorganic Salts, ...	0·7	
		13·0
		100·0

The casein present in the milk plasma forms a denser layer round each fat-globule, constituting a sort of envelope. This can be broken down by shaking up the milk with caustic potash or acetic acid, and if after this ether[1] is added it can get at the fat and readily dissolves it, whereas when shaken up with fresh milk not thus treated it has no effect. The experiment is considered to prove the presence of investments to the fat-globules, but these coverings must not be thought of as firm skins. Owing to the relative lightness of the fat-globules they rise to the surface when milk is allowed to stand, and make up a large part of the **cream.**

---

[1] A very volatile liquid which possesses in a marked degree the power of dissolving fat or oil.

Rennet, which is prepared from the fourth division of the calf's stomach, contains the ferment **rennin**, and when added to milk this ferment causes the separation of the **curd**, which mainly consists of casein. A similar process takes place in the human stomach as the first stage in the digestion of milk (p. 75).

It will be seen, from the preceding chemical analysis, that milk contains representatives of all the essential food-constituents, and these are in the proportion necessary to constitute a **perfect food** for the young calf, as indeed follows from the nature of the case. The albuminoid ratio (taking the whole as digestible) is easily calculated to be about 1 : 3·4. A sucking calf does not ruminate, in fact the first three chambers of its stomach are only slightly developed, and digestion is carried on much in the same way as in a human being (p. 74). Such a calf is obviously incapable of feeding on grass, hay, and the like.

Structure of the Udder (fig. 104). — The cow's udder consists of four **milk** or **mammary glands**, each provided with its own separate **teat.** The four glands are bound together by a firm sheath of connective tissue, which is continued into a firm vertical partition or septum which separates the glands of opposite sides. The same kind of tissue divides less clearly the front gland on each side from the corresponding back gland, and enters into the glandular substance as a supporting framework traversed by blood-vessels, nerves, and lymphatics. Each gland chiefly consists of a very large number of branched tubules (somewhat on the plan of fig. 47, 6), the twigs of which terminate blindly in small swellings placed to one side (some of these are seen at T, fig. 104), and lined by a single layer of glandular epithelium. By the successive union of these tubules larger

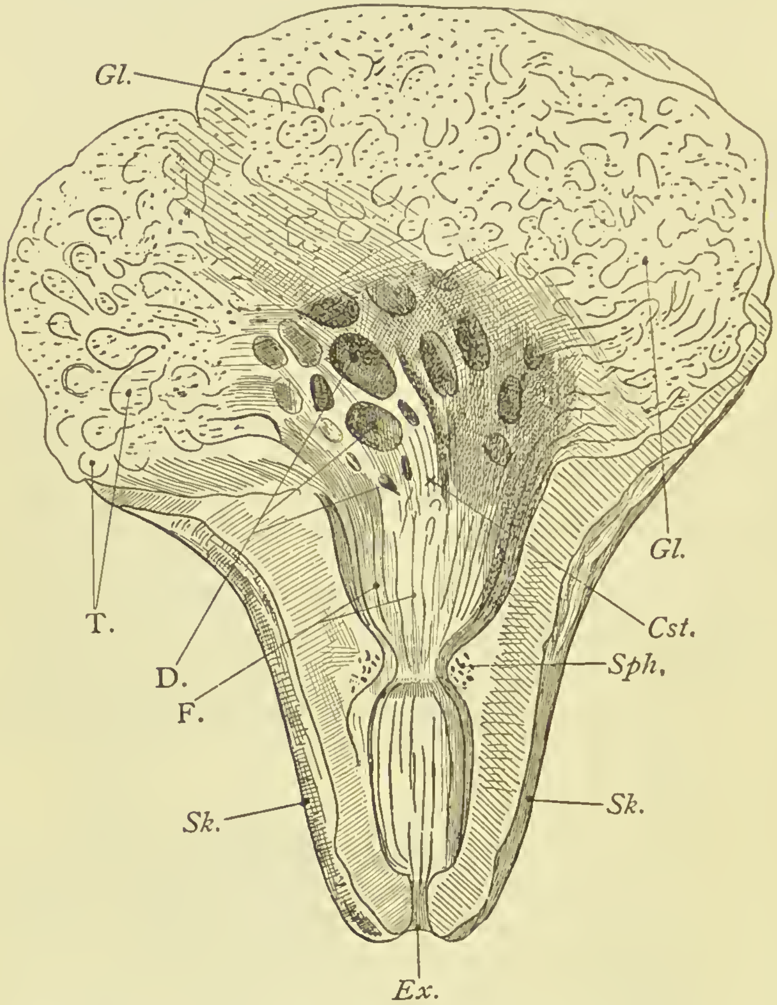

Fig. 104.—Structure of Udder. [After Thanhoffer.]

One teat and part of adjacent gland are cut through. *Gl*, Glandular tissue; T, blind endings of milk tubules; D, openings of large milk ducts into milk cistern, *Cst.*; F, folds in large milk ducts; *Sph.* sphincter muscle, cut through; *Sk.* skin of teat; *Ex.* opening of teat-cavity to the exterior.

"**milk-ducts**" are constituted which open into a good-sized "**milk-cistern**" situated at the base of the teat. This cavity narrows below to a small hole, which is usually kept closed by a **sphincter** or **ring-muscle** (*Sph.*), and below this again is another cavity opening to the exterior by a narrow passage which runs to the end of the teat (*Ex.*).

Secretion of Milk.—The milk-glands are not merely to be regarded as arrangements by which certain materials are strained out of the blood. The milk-tubules are very closely surrounded by a network of capillary blood-vessels, and constitute a filtering apparatus so far as the water contained in milk is concerned. But that a great deal more than simple filtration takes place follows from the fact that casein, milk-sugar, and butter-fat are not present in blood, while there are considerable differences between the two liquids as regards the inorganic salts, milk containing, for example, far less sodium chloride than blood, but being much richer as regards potash compounds. In short, the **protoplasm** of the glandular cells which line the blind ends of the milk-tubules breaks down into the simpler chemical substances, casein, milk-sugar, butter-fat, &c., which are therefore produced much in the same way as the pepsin of gastric juice or the ptyalin of saliva. But in this case there is not only a chemical breaking-down of protoplasm, but also a *disintegration of the cells*, which, so to speak, are constantly "moulting". For this reason milk has been termed "dissolved milk-gland", using the expression somewhat metaphorically. An interesting proof of this is found in the nature of **colostrum**, the fluid which is secreted by the milk-glands just after the birth of the calf, and which differs a good deal from milk in composition. If a drop of this is examined under the microscope (fig. 103, II) it will be found to contain not only milk globules but also larger bodies, **colostrum corpuscles**—some spherical, some irregular—which are obviously discarded cells. The constant breaking-down which takes place in a milk-gland is counterbalanced by a corresponding process of renewal and reconstruction, the materials for which are supplied by the blood.

During milking the **sphincter muscle** of the teat is relaxed as the result of reflex action, so that the milk can flow out of the milk cistern. It has also been commonly assumed that a large amount of milk is actually secreted *during* milking, as another result of reflex action. The main argument in favour of this view has been that the cavities of the glands are not large enough to contain the amount of milk actually yielded at one time. It must be remembered, however, that these organs are very elastic and capable of great distension, besides which careful experiments recently made do not support the usual view.

Factors Influencing the Amount and Quality of Milk.—In this connection (1) the **breed** is of very great importance, determining as it does the tendency of the glands to secrete a greater or less total quantity, and to produce milk more or less rich in butter-fat, &c. (2) **Diet.** The essential point is that the food should be rich in albuminoids, the most favourable ratio being 1: 5·4 (p. 199). It is quite a mistake to suppose that an increased percentage of butter-fat in the milk results from giving more fat or oil with the food. Careful experiments made on the feeding of cows show that if anything the tendency is the other way. From what has already been said on the secretion of milk it follows that the fat of the food does *not* pass as such into the milk, a fact which enables the experiments quoted to be more clearly understood. A reasonable amount of water taken with the solid food increases the secretion of milk, and a favourable influence is also exerted by common salt, of which from ½ to ¾ of an ounce may with advantage be given daily to each cow. (3) The state of the **general health** naturally exerts an important influence upon the production of milk, for all the organs of the body are more or less interdependent. It is therefore a matter of practical importance to secure the health of cows not only by feeding them properly but also by attending to ventilation, cleanliness, and other matters of the kind. Some interesting experiments made as to the effect exerted by proper care of the coat may be taken as an illustration. The amount and quality of milk yielded by a number of cows were carefully determined for two periods of a fortnight each, no attention being paid to the coat during one period, while during the other it was carefully brushed and currycombed every day. In the latter case the yield of milk was considerably greater, and there was a distinct increase in the percentage of butter-fat. As might be anticipated, the yield is diminished by exercise, the amount of which should not, therefore, be increased beyond that actually necessary for the maintenance of health. (4) The quantity and quality are not constant throughout the period of milk-yielding or **lactation.** The maximum quantity is secreted during several weeks after the birth of the calf, and then a gradual diminution takes place. At the same time the proportion of albuminoids gradually increases while the proportion of sugar and butter-fat diminishes. For English cattle the average period of lactation is 250 days, during which time about 2652 quarts of milk are secreted.[1] (5) **Time of milking.** The morning milk is poorer in solids than the evening milk, while that obtained at noon is richer than either. In other words, the longer milk remains in the udder the poorer it is in quality, though at the same the quantity is greater. Experiment has also shown that three milkings per day are more advantageous than two, the total yield being greater and the percentage of butter-fat higher.

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[1] Schmidt-Mülheim.

INDEX.

pl. = plural.

Abdomen, 10, 12, 15, 16, 61, 62, 69, 93, 102, 106; of rabbit, 171, 172, 173, 184.
Absorption, chap. iv.; of digested food, 76, 80, 112, 197, 198; of oxygen, 16, 80, 112.
Accommodation of eye, 164, 188.
Acetabulum, 37.
Acid, 49, 117, 132, 135; acetic, 180, 187, 190, 200; carbonic, *see* Carbon dioxide; hydrochloric (*or* muriatic), 18, 74, 108, 180, 181; nitric, 179; sulphuric, 52, 53, 184; tastes, 149.
Acuteness of sense of contact, 147, 186.
"Adam's apple", 26, 103.
Adjustments of microscope, 189.
Afferent, 131, 132.
Air, 48, 51, 52, 53, 60, 105, 106, 107, 112, 113, 114; cell, 104; complemental, 107; expired, 107, 110, 126, 184; inspired, 107, 110, 184; passages, 106, 111; residual, 107; sac, 104, 105, 111, 112, 113; supplemental, 107; tidal, 106, 107, 111.
Albumin, 55.
Albuminoid ratio, 198, 199, 201, 204.
Albuminoids, 198, 199, 200, 204, 205; *and see* Proteids.
Alimentary canal, 15, 56, 63, 73, 77; of ox, 192; of rabbit, 172, 173, 174–176.
Alkali, 49, 117.
Alkaline tastes, 149.
Alveolus, 68.
Ammonia, 115, 116, 179, 185.
Ammonium carbonate, 115.
Ampulla, 157.
Amylolytic, 73.
Amylopsin, 75.
Analysis, 47, 108; of hay, 198; of milk, 200; *and see* Composition.
Anatomy, 8.
Animal, 7, 53, 54; diet, 78; matter of bone, 19.
Ankle, 10, 20, 41, 44.
Anvil, 154.
Appendages, of auricles, 86, 181.
Arachnoid membrane, 128.
Arbor vitæ, 137, 178.
Arch; of aorta, 93, 176, 177; of cranium, 22; of foot, 39; of lower limb, 38; neural, 28; zygomatic, 24.
Arm, 10, 41; arm-pit, 123.
Artery, 80, 87, 95, 96, 97, 98, 100, 112, 124; aorta, 88, 90, 92, 93, 120, 173, 176; dorsal aorta, 93, 173; carotid, 93, 97, 174, 177; coronary, 93, 94, 183; iliac, 93; pulmonary, 88, 89, 90, 92, 93, 112, 176, 181, 182; of rabbit, 172, 173, 174, 177; renal, 120; of sheep, 181, 182, 183; subclavian, 93.
Articulation, *see* Joint.
Ash, 55, 198.
Asphyxia, 113.
Atlas, 28, 41.
Atom, 48, 54.
Atomic theory, 48.
Auricle, 86, 87, 88, 89, 90, 91, 92, 181, 182, 183.
Auricular septum, 86, 182.
Auriculo-ventricular opening, 86, 89 90, 182.
Automatic actions, 140.
Automatic nerve-centre, 141.
Axis; vertebra, 29, 41; of brain, 135, 136, 178.

Back, 9, 122; "broken", 134; of foot, 147; of hand, 147.
Backbone, *see* Vertebral column.
Baker, C., 170, 189.
Bean, 55.
Beat, 90.
Beating, 92.
Belly, *see* Abdomen; of a muscle, 42, 72.
Biconvex lens, 161, 162.
Bicuspid teeth, 58.
Bile, 75, 76, 197; salts, 75.
Biology, 7, 8.
Bitter tastes, 149.
Black-lead, 48.
Bladder, 76; gall, 69,—of rabbit, 173,—of ox, 194; urinary, 16, 118.
Bleeding, 83.
Blind spot, 160, 166, 167, 187, 188,
Blood, 15, 55, 65, 77, 80, 81, 83, 84, 86, 89, 91, 92, 94, 95, 96, 112, 120, 128,

183, 190; corpuscles, 81, 190; impure (venous), 87, 88, 112, 113, 141; pure (arterial), 87, 88, 112, 113; system, 80, 81; vessels, 14, 15, 17, 18, 42, 56, 59, 63, 69, 76, 77, 80, 84, 85, 92, 95, 101, 102, 141, 142, 159, 160, 170, 172, 173, 174, 176, 201, 203.
Blow-pipe, 170.
Body; composition of, 55; of vertebra. 28
Bone, 17, 47, 55; compact, 18, 19, 25, composition of, 18; earth, 55; physical properties of, 19, 25; spongy, 18, 19, 25.
Bones; astragalus (huckle), 39; atlas, 28, 41; axis, 29, 41; calcaneum (heel), 39; carpus (wrist), 22, 35, 41; clavicle (collar), 20, 30, 33; coccyx, 27; cranial, 22, 24; ethmoid (consisting of cribriform plate, vertical plate, and lateral mass divided into upper and middle turbinated bones), 24, 150; facial, 25; femur, 17, 20, 37; fibula, 20, 38; flat, 20; frontal, 22; hip girdle, 36; humerus, 20, 34, 41; hyoid, 26, 72; innominate, 20, 36; irregular, 20; lachrymal, 25; as levers, 41; limb, 33, 36; long, 20; malar, 25; maxillary (upper and lower), 25; metacarpus, 22, 36, 41; metatarsus, 22, 39; nasal, 25; occipital, 23, 41; palate, 25; parietal, 22; patella, 20, 38; pelvis, 37, 44; phalanges, 22, 36, 39; radius, 20, 34, 41; ribs; 20, 27, 30, 31, 92, 105, 184; sacrum, 27; scapula (shoulder blade), 20, 33; shoulder girdle, 33; sphenoid, 24; inferior spongy (turbinated), 25, 150; sternum (breastbone), 20, 30, 31, 105, 184; tarsus (ankle), 22, 39; temporal (divided into mastoid, petrous, and squamous parts), 23, 71, 72, 152, 154, 155; tibia (shin), 20, 38; turbinated (of rabbit), 178; ulna, 20, 34, 35; vertebrae, 27, 28, 60; vomer, 25; zygoma, 24; zygomatic arch, 24, 71, 72.
Brain, 131, 133, 134, 135–142, 143, 146, 150, 156; axis of, 135, 136; functions of, 139–142; mid, 136, 139, 141, 166; outgrowths from, 137, 139; of rabbit, 177, 178; 'twixt, 136, 137, 139, 141.
Bread, 78, 79, 80.
Breed of cows, 204.
Brimstone, *see* Sulphur.
Bronchial tubes, 104, 111.
Bronchus (*pl.* bronchi), 102, 103; of rabbit, 177.
Bullock's eye, 187.
Burroughs, Wellcome, & Co., 179, 180, 181.
Butter-fat, 200, 201, 203, 204, 205.

Cæcum, 62, 65; of ox, 194; of rabbit, 172.
Calcium (Ca), 55.
Calf, 181, 201, 205.
Camera, 162, 163, 164.
Canal; alimentary, 15, 56, 63, 73, 77,—of ox, 192,—of rabbit, 172, 173, 174-176; central canal of spinal cord, 129, 136; Haversian, 18; neural, 127, 131; spinal, 28.
Candle, 51, 53, 109, 165, 188.
Canine teeth, 56; of ox, 193, 195.
Capillaries, 77, 80, 93, 94, 95, 97, 98, 105, 111, 112, 119, 120, 198, 203.
Capsule of lens, 161, 187.
Carbohydrates, 54, 55, 56, 79, 94, 124, 198, 199, 200.
Carbon, 48, 53, 54, 55, 78, 79, 108, 112, 113, 115; dioxide, 48, 49, 51, 87, 101, 107, 108, 109, 110, 111, 114, 184.
Cardiac cycle (revolution), 90, 91.
Cardiac end of stomach, 60, 191.
Cardiac impulse, 92, 183.
Care of coat, in cows, 204, 205.
Carnivorous animals, 54.
Cartilage, 17, 18, 40, 47, 95, 177; properties of, 19.
Cartilages; costal, 30; cricoid, 103; thyroid, 102; of trachea and bronchi, 103.
Casein, 55, 75, 200, 201, 203.
Cat, 8, 26, 140.
Cauda equina, 130.
Caustic potash, 200.
Cavity: abdominal, 117, 172, 194; body or ventral, 12, 81; dorsal, 11, 127, 128; glenoid, 24, 26, 33; mouth, *see* Mouth; nasal, 25, 56, 60, 71, 74, 106, 114, 145, 149, 151, 158; pelvic, 63; of pharynx, 60; pulp, 59; of cow's teat, 202; thoracic, 101, 173; of trunk, 11; tympanic, 153, 154, 155, 156, 178.
Cell, 64, 67, 83; auditory, 155, 156, 157; central (chief), 66; goblet, 65; liver, 70, 191; nerve, 129, 142, 160; olfactory, 150, 151; parietal, 66; sense, 144, 148, 151, 155; taste, 148; visual (rods and cones), 160, 166, 167, 191.
Cement, 60; in teeth of ox, 193, 196.
Central organs, 17, 127.
Centrum, 28.
Cerebellum, 137; of rabbit, 178, 179.
Cerebral convolutions, 138.
Cerebral hemispheres (cerebrum), 137, 138, 139, 141, 142; of rabbit, 177, 178.
Chalk, 55, 108.
Chamber; of eye, 159; posterior nasal, 175, 178.
Charcoal, 48, 51, 53, 54.
Cheeks, 57, 71, 147; of ox, 195.
Cheese, 54, 55, 78.
Chemistry, 48, 108, 169; organic, 53; physiological, 179–181.
Chest, 10.
Chewing, *see* Mastication.
Child, 19, 143, 146.

Chin, 72.
Chlorine (Cl), 55.
Chordæ tendineæ, 87, 182.
Choroid, 159, 164, 165, 187.
Chyle, 76, 78.
Chyme, 74, 75.
Cilium (*pl.* cilia), 105, 191.
Circulation, 15, chap. v., 183; course of the, 92; in frog's foot, 184; greater (*or* systemic), 93; lesser (*or* pulmonary), 93; proofs of the, 97.
Circulatory organs, 15, chap. v., 126.
Classes of levers, 43, 45.
Cleanliness, 204.
Clot, 83.
Clothes, 124.
Clotting, *see* Coagulation.
Clouds, 108.
Coagulation; of blood, 83, 84, 183.
Coats; of blood-vessels; of eye, 159, 187, 188; of intestine, 63; of stomach, 65, 176.
Cochlea, 157.
Cold, 132; cold-blooded animals, 133; cold spots, 186.
Colds, 152.
Colon, 62, 63, 65; of ox, 194; of rabbit, 172.
Colostrum, 203.
Coloured pencils, 170.
Columnæ carneæ, 89, 182.
Columns of spinal cord, 129.
Combustion, 51, 53, 109, 125.
Compasses, 186.
Composite teeth, 193.
Composition; of air, 108; of inspired and expired air, 110; of body, 47; of food, 47, 78; of hay, 198; of milk, 200; of sweat, 123; of urine, 115.
Compound, 48.
Concha, 10, 153, 155.
Condyle; of lower jaw, 26,—in ox, 196; occipital, 23, 44, 72.
Cones, *see* Cells, visual.
Consciousness, 143.
Contact, 131, 144, 145, 146, 147, 186.
Contractility, 14, 41, 72, 73, 105.
Contraction, 14; of muscles, *see* Contractility.
Convulsions, 114, 134.
Cornea, 159, 165, 187, 188.
Cornu (*pl.* cornua); anterior and posterior cornua, 129.
Corpus callosum, 138.
Corpuscles; blood, 81, 84; colostrum, 203; red, 81, 82, 83, 98, 101; touch, 145; white (*or* colourless), 81, 83, 84, 98, 101.
Correlation, 16, 127.
Cortex; of cerebellum, 137; of cerebrum, 138, 142, 144, 155, 167; of kidney, 118, 119, 120, 185.
Coughing, 74, 114, 140.
Coughs, 152.
Cover-slips, 188, 190.
Cow, Digestion and Secretion of Milk in, chap. xii.
Cranium (brain-case), 9, 20; bones of, 22.
Cream, 201.
Cremation, 55.
Crown of tooth, 59.
Cricoid cartilage, 103.
Crura cerebri, 136.
Cud, 195, 196, 197; chewing the cud, *see* Rumination.
Curd, 75, 181.
Cutting teeth, *see* Incisor teeth.

Death; general, 126, 127, 133, 140; local, 125.
Decapitation, 133.
Decomposition, chemical, 49, 124.
Deglutition, *see* Swallowing.
Dentine, 59; in teeth of ox, 193, 196.
Dentition, 58.
Dermis, 14, 121, 122, 123, 145.
Diagrams, 171.
Dialyzer, 76, 179, 180.
Diamond, 48, 53.
Diaphragm, 12, 60, 69, 84, 102, 105, 130, 172, 173, 176, 184, 194; of microscope, 188, 189.
Diastole, 91; auricular, 91; ventricular, 91, 98.
Diet, 78–80, 192; of cows, 204.
Differentiation, 13.
Diffusion, 76, 77, 80, 111, 112, 179, 180, 181.
Digestible fodder constituents, 198.
Digestion, 14; chap. iv. 179–181; in cow and ox, chap. xii.; in the intestine, 75; in the mouth, 71; nature of, 57; in the stomach, 74.
Digestive organs, 15, chap. iii.; of cow and ox, chap. xii.; of rabbit, 174–176.
Digit, 10, 11, 36.
Diploë, 25.
Disc, intervertebral, 28.
Dissecting dish, 170.
Dissection, 8, 170, 171; of eye, 187, 188; of rabbit, 171–178; of sheep's heart, 181–183.
Distal, 34.
Distribution of heat, 126.
Division of labour, 13, 127, 140.
Dog, 8, 26, 140.
Dorsal, 9.
Drawing, 170, 171.
Drinking, in ox, 195.
Drum of ear, *see* Cavity, tympanic.
Duct, 66; bile (of rabbit), 176,—(of ox), 194, 195; common bile, 70; cystic, 70; hepatic, 69, 71; lachrymal, 25; pancreatic, 70, 71,—of ox, 195,—of rabbit, 176; parotid, 68; sublingual, 68,

175; submaxillary, 68, 175; of sweat-gland, 122; tear, 158; thoracic, 101, 198.
Dung, 198.
Duodenum, 61, 70, 71; of ox, 194, 195; of rabbit, 176.
Dura mater, 128, 177.
Dust, 151.
Dyspnœa, 114.

Ear, 10, 23, 24, 67; external, 153; internal, 154–157; middle, 153, 154; of rabbit, 178.
Education, 144.
Eggs, 54, 55, 78; white of egg, 179, 180.
Elasticity; of arteries, 98; of lungs, 106.
Elbow, 34, 40, 41, 45.
Electric current, 131, 132.
Elements, 48.
Emulsion, 75, 76, 77, 181, 200.
Enamel, 60; in teeth of ox, 193, 196.
Endolymph, 154.
End-organs, *see* Cells, sense.
Energy, 14, 16, 114; kinetic (*or* actual), 14, 125; potential (*or* stored), 14, 125.
Eosin, 190.
Epidermis, 14, 64, 95, 121, 122.
Epiglottis, 60, 74; of rabbit, 175.
Epithelium, 64, 65, 77, 80, 95; ciliated, 105, 191; columnar, 104, 190, 194; glandular, 66, 70, 110, 120, 121, 191, 194, 202; sensory, 145, 148, 151, 155, 191; simple, 95, 105, 119; squamous, 105, 190; stratified, 67, 121, 122, 148, 151, 190, 194.
Erect position, 127.
Ether, 185, 200; of space, 162.
Eustachian tube, 60, 154, 156; of rabbit, 175.
Excentric reference of sensations, 146.
Excretion, 16, 81; chap. vii., 184, 185.
Excretory organs, 81, 121, 184, 185.
Exercise, 124, 205.
Expiration, 32, 105, 106, 107, 110, 114.
Extension, 41.
Eye, 114, 157–168; eye of rabbit, 178; eye of sheep (or bullock), 187, 188; socket, *see* Orbit.
Eyeball, 158–161.
Eyebrow, 157.
Eyelash, 157.
Eyelid, 147, 157, 158; of rabbit, 178.
Eyepiece of microscope, 188, 189.

Face, 9, 22, 139.
Fæces, 57, 126.
Fainting, 127, 143.
Fang of a tooth, 59.
Fasciculus (*pl.* fasciculi), 42.
Fat, 47, 54, 55, 56, 73, 75, 76, 77, 78, 79, 94, 100, 123, 124, 158, 182, 184, 187, 198, 199, 200, 201, 203, 204, 205; emulsification of, 181; globules of milk, 200, 201, 203.
Fatigue, 144.
Feeding of stock, 198, 199.
Fehling's solution, 179, 180.
Fenestra; ovalis, 155; rotunda, 155, 156
Ferment, 72, 73, 74, 75, 76, 84, 180, 181.
Fermentation, 72, 73, 74, 75, 76, 84.
Ferrous sulphate, 113.
Fibre; afferent nerve, 131, 141; efferent nerve, 131; motor nerve, 131, 132; muscle, 42; nerve, 129, 130, 131; sensory nerve, 132, 144, 145; woody, 198.
Fibrin, 55, 83, 84, 181, 183; ferment, 84.
Fibrinogen, 84.
Filum terminale, 128.
Finger, 11, 36, 39, 121, 122, 145, 147.
Fissures of spinal cord, 128.
Flavours, 149, 152.
Flesh, *see* Muscle.
Flexion, 41.
Flexure, sigmoid, 62.
Flour, 55.
Flow of blood, rate of, 97.
Fluid; cerebro-spinal, 128; synovial, 40.
Fodder, 198, 199.
Fog, 108.
Food, 15; chap. iii., 71, 72, 73, 74, 78, 125; chemical classification of, 54, 78; composition of, 47; mineral, 54, 55, 56, 73, 79; of stock, 198, 199; tube, *see* Canal, alimentary.
Foot, 10, 44, 45, 121, 122, 145.
Foot-pound, 92.
Foot-ton, 126.
Foramen (*pl.* foramina); intervertebral, 28, 130; magnum, 22, 23, 128; nutritive, 18.
Forceps, 170; bone, 170.
Forearm, 10, 41, 42, 45.
Formula; chemical, 49; dental, 58,—of ox, 193.
Fragrant smells, 151.
Fritsch, Dr., 170.
Frog, 98, 133, 135, 137, 139, 140, 141, 142, 183, 184, 185, 191.
Front, 9.
Fulcrum, 43.
Functions, 7; general sketch of, 13.

Gall, *see* Bile.
Ganglion (*pl.* ganglia), 131; spinal, 130; sympathetic, 127, 142, 174; vagus, 174.
Gas, 76, 151.
Gastric juice, 66, 74, 75, 181, 182, 197.
Gelatin, 55.
Gilbert Williams, H. W., 171.
Ginger-beer, 48.
Girdle, 20; hip, 20; shoulder, 20.
Gland, 64, 65, 67, 68; ductless, 101; gastric (peptic), 66, 191; of Lieberkühn, 63, 65; lymphatic, 101; mesenteric, 101; milk (mammary) gland of

cow, 201–204; parotid, 67, 174; salivary, 67, 68,—of ox, 193,—of rabbit, 174; sebaceous, 121; sublingual, 68; submaxillary, 68, 174; sweat, 122, 124; tear, 158; thymus,—of rabbit, 173, 176.
Globin, 112.
Glomerulus (*pl.* glomeruli), 119, 120.
Glottis, 60, 74, 102, 105, 106, 114; of rabbit, 175.
Glucose (grape-sugar), 179.
Gluten, 55.
Glycerine, 180, 181, 190.
Glycerinum pepticum, 180.
Goat, 196.
Graphite, 48, 53.
Grass, 199, 201.
Grazing, 74, 195.
Grey matter, 131; of brain, 136, 137, 138, 142, 155, 166, 178; of spinal cord, 129, 134, 135.
Grinding teeth, 71; of ox, 193, 195, 196. *See also* Premolar and Molar.
Gristle, *see* Cartilage.
Growth, 15, 18.
Gullet (œsophagus), 15, 60, 61, 63, 67, 73; of ox, 193; of rabbit, 173, 175.
Gum, 55.
Gums, 57, 58.
Gymnema sylvestre, 149.

Hæmatin, 112.
Hæmoglobin, 82, 112, 113; oxy-, 112, 113; reduced, 112, 113, 114.
Hair, 14, 95, 121; auditory, 155, 156; sac, 121.
Hammer (malleus), 154.
Hand, 10, 42, 121, 122, 131, 145, 147.
Hartshorn, spirits of, 116.
Haversian canals, 18.
Hay, 198, 199, 201.
Head, 9, 20, 130, 145; of femur, 37; of fibula, 38; of humerus, 34; of radius, 34; of tibia, 38; of ulna, 35.
Health of cows, 204.
Hearing, 17, 139, 144, 152–157, 187.
Heart, 80, 84, 85, 86, 101, 102, 105, 114, 119, 127, 139, 140; external characters of, 88; interior of, 88, 90; of rabbit, 173, 176, 183; of sheep, 181–183; work of, 92.
Heat, 16, 108, 114; animal, chap. viii., 131, 132.
Heel, 11, 39, 45.
Herbivorous animals, 54.
Hilus, 118, 119, 120, 184.
Hip, 10, 11, 38, 41.
Histology, 8, 188–191.
Honeycomb bag (reticulum), 194, 196, 197.
Hot spots, 186.
Humours, aqueous and vitreous, 161, 163, 167, 187.
Hydrogen, 48, 49, 52, 53, 54, 55, 112, 115, 116.

Ileum, 61, 65.
Illusions, 147.
Image; formation of image in eye, 162, 163, 188; mirror, 9.
Incisor teeth, 58, 68, 71; of ox, 193, 195.
India-rubber, 180.
Inhibition, 142.
Injury to blood-vessels, 97, 112.
Inorganic salts; of milk, 200, 203.
Insensible perspiration, 123.
Insertion of a muscle, 43.
Inspiration, 31, 105, 106, 107, 110, 114.
Intelligence, 140, 142.
Intestinal juice, 75, 76.
Intestine, 15, 56, 63, 67, 69, 77, 80, 94, 100; large, 15, 61, 62, 64, 65,—of ox, 194, 197,—of rabbit, 172, 176; small, 15, 61, 63, 64, 65, 191.
Iodine, 179.
Iris, 159, 160, 165, 187, 188.
Iron (Fe), 55, 112.
Iter, 136.
Ivory, *see* Dentine.

Jaw, 9, 22, 24, 68, 71, 72, 196.
Jejunum, 61.
Joints, 17, 19, 40, 41; ankle, 41, 44; ball-and-socket, 34, 38, 41; elbow, 34, 40, 41, 45, 177; hinge, 26, 29, 35, 38, 40: double hinge, 41; hip, 11, 38, 41; imperfect, 40; knee, 38, 41; lower jaw, 71, 72, 196; oil, 40; perfect, 40; pivot, 41; shoulder, 11, 34, 41, 177; synovial, 40.

Kidney, 15, 16, 115, 117, 118, 119; of rabbit, 172, 173; of sheep, 184, 185.
Knee, 38, 41; pan (patella), 38.

Labyrinth; bony, 157; membranous, 157.
Lactation, in cow, 205.
Lacteals, 75, 77, 78, 100, 101, 198.
Larynx, 60, 102, 114, 139; of rabbit, 174.
Lavender, 151.
Leg, 10, 44, 45; movements of, 41.
Legumin, 55.
Leitz microscope, 189.
Lens, 162, 163, 164, 168; of eye, 161, 163, 164, 165, 167, 168; hand, 170; of microscope, 188, 189.
Lentil, 5.
Letter-clip, 186.
Leucocyte, *see* Corpuscle, white.
Lever, 20, 43, 44, 45, 72.
Ligament, 17, 42, 47; check, 29; ligamentum nuchae, 30, 47; round (liga-

mentum teres), 38; suspensory ligaments of eye, 161, 164; transverse, 29.
Light, 159, 162, 163, 165, 166, 167.
Limbs, 10, 11, 130.
Lime; carbonate of, 55, 108, 109; phosphate of, 55, 58; slaked, 116; water, 109, 110.
Limestone, 108, 109.
Lips, 57, 147; of ox, 192.
Liquids, 76.
Litmus, 49, 117.
Liver, 15, 69, 70, 94, 95, 106, 139; of ox, 194; of rabbit, 172.
Lobe, 69; olfactory lobe of rabbit, 177; optic, 136,—of rabbit, 178.
Lobule, 68, 70, 104.
Long sight, 168.
Lungs, 15, 16, 84, 87, 93, 101, 102, 105, 106, 110, 111, 112, 139; of rabbit, 172, 173, 177, 184.
Lymph, 80, 81, 85, 102, 112, 128; system, 80, 81.
Lymphatics, 81, 100, 123, 201.

Malpighian body, 119, 185.
Malpighian layer, 121.
Malt, 72.
Maltose, 72, 179.
Manganese, black oxide of, 50.
Manyplies (psalter, omasum), 194, 197.
Marble, 108.
Marrow, 18.
Mastication (chewing), 26, 71; in ox, 195, 196, 197.
Meat, 54, 55, 78, 79, 80.
Meatus, external auditory, 153, 155, 156.
Mechanics, 8, 43.
Medulla; of kidney, 118, 119, 120, 185; oblongata, *see* Spinal bulb.
Meller, H., 169, 191.
Membrane; of brain and spinal cord, 128, 177; elastic, 95; hyaloid, 161, 167, 187; mucous, 56, 57, 63, 64, 65, 66, 67, 74, 76, 148, 150, 180, 193, 194; synovial, 40; tympanic, 153, 154, 155, 156, 178.
Mercury (Hg.), 50.
Mesentery, 56, 101; of rabbit, 172.
Metabolism, chap. viii.; constructive and destructive, 125, 126.
Microscope, 8, 98, 188, 189.
Midriff, *see* Diaphragm.
Milk, 75, 76, 78, 79, 181, 200–205; characters of, 200, 201; cistern, 202, 204; curdling ferment (rennin), 74, 181, 201; ducts, 202; (*or* mammary) glands, 201–204; secretion of, 203, 204, 205; sugar, 200, 203, 205; tubules, 201, 202, 203; variations in quantity and quality of, 204, 205.
Milking, 204, 205.
Millstones, 195.
Mineral; food, 54, 55, 56, 73, 79; matter of bone, 19. *See also* Ash and Inorganic salts.
Mixed diet, 79.
Mixed nerves, 132.
Mixtures of food for stock, 199.
Models, 170.
Molar teeth, 58.
Molecular vibrations, 131, 144, 150, 151, 155, 167.
Molecule, 49, 54.
Morphology, 7, 8.
Motor centres, 142.
Moulting, of milk-cells, 203.
Mouth, 12, 15, 22, 57, 68, 71, 72, 106, 114, 139, 145; of ox, 192; of rabbit, 175.
Movement, 14, 134; of eyeball, 167, 168; of heart, 183; of limbs, 11; reflex, 135, 141; of respiration, 105, 127, 140, 184; voluntary, 142.
Mucus, 65, 105.
Muscle, 14, 42, 63, 96, 133, 185, 186; bundle (fasciculus), 42; fibre, 42; involuntary (white), 46, 63, 65, 67, 73, 95; nerve preparation, 89, 90, 182, tonic state of, 46; voluntary (red), 46, 58, 67.
Muscles, 14, chap. ii., 84, 127, 130, 131, 177; biceps, 41; calf muscle (gastrocnemius), 44, 133; ciliary, 164, 165, 187; of diaphragm, 105, 172; digastric, 72; expiratory, 33, 114; extensor, 45; eyeball, 139, 158, 167, 168, 175; of face, 139; flexor, 48; hollow, 84; inspiratory, 32; intercostal, 32, 177; jaw, 71, 72, 139; masseter, 71, 72; oblique, 168; papillary, 89, 90, 182; of pharynx, 139; of rabbit, 171, 172, 174, 177, 178; rectus, 167; ring, *see* Sphincter; temporal, 71, 72; of tongue, 139; maintaining upright position, 46.
Muscular sense, 169.
Musk, 151.
Muzzle of ox, 192.
Myosin, 55.

Nails, 10, 14, 95, 121.
Nares; external (nostrils), 150; posterior, 60, 74, 106, 149, 175.
Narrow albuminoid ratio, 199.
Neck, 10, 12, 20, 60, 102, 103, 130, 139, 147; of rabbit, 171, 174; of tooth, 59.
Needles, 170.
Nerve, 185, 186; centre, 134, 135, 139, 140, 141, 142, 143, 144, 155; impulse, 132, 133, 134, 135, 140, 144; muscle-nerve preparation, 89, 90, 182.
Nerves, 17, 42, 59, 63, 69, 123, 127, 201; abducent, 139; afferent, 134, 140, 166; auditory, 139, 153, 155, 156, 168; cranial, 139, 140, 142; efferent, 134, 166; facial, 139; glossopharyngeal,

139, 149: hypoglossal, 139; lingual, 149; mixed, 132, 139; motor, 139, 185; oculo-motor, 139, 166; olfactory, 139, 150; optic, 139, 160, 166, 167, 168, 178, 187; pathetic, 139; phrenic, 130, 173; secretory, 124; sensory, 139, 144, 145, 149, 150, 153, 155; spinal, 130, 132, 134, 142, 145, 178, 185; spinal accessory, 139; sciatic, 133, 186; sympathetic, 17, 142, 166, 174; trigeminal, 139, 145, 149, 151; vagus, 139, 141, 173, 174; vaso-motor, 100, 124, 140.
Nervous system, 17, 123, chap. ix.; central, 127; peripheral, 127; of rabbit, 177, 178; sympathetic, 142, 174.
Nitrogen, 48, 51, 52, 54, 55, 78, 79, 108, 112, 115, 116.
Nitrogenous food, 54.
Nitro-glycerine, 14.
Non-nitrogenous food, 54.
Normal salt solution, 190, 191.
Nose, 12, 22, 114, 139, 145, 147, 150; of rabbit, 178.
Nucleus, 64, 83, 190.

Oatmeal, 74, 79.
Objectives, 188, 189.
Odours, 151.
Œsophagus, *see* Gullet.
Oil, 53, 55, 75, 181, 200; cake, 199.
Old people, 19.
Omasum, *see* Manyplies.
Omnivorous animals, 54.
Onion, 187.
Optic thalamus (*pl.* thalami), 136.
Orbit, 22, 24, 25, 157, 158, 168.
Organic matter, 110, 113, 184.
Organs, 7; general sketch of, 13.
Origin of a muscle, 43.
Ossicles, auditory, 154, 155, 178.
Otolith, 155, 156.
Ox, 8, 30; digestion in ox, chap. xii.
Oxidation, 5, 113, 125, 126.
Oxygen, 16, 48, 49, 50, 52, 53, 54, 55, 87, 101, 107, 108, 110, 111, 112, 114, 115.
Oxy-hæmoglobin, 112, 113.

Pain, 132, 144, 168.
Palate, 24; hard, 25, 57, 175; soft, 57, 74, 150, 175.
Palm of hand, 122, 145, 147.
Pancreas, 70, 71, 94, 191; of ox, 194; of pig, 181; of rabbit, 176.
Pancreatic juice, 75, 76, 181, 182, 197.
Papilla (*pl.* papillæ); circumvallate, 148, 175; of dermis, 123, 145; filiform, 148, 175; foliate, 175; fungiform, 148, 175; of paunch, 193; of tongue, 148, 175; urinary, 119, 185.
Parchment, vegetable, 76.
Paunch (rumen) of ox, 193, 195, 196, 197.
Pax wax, 30.
Peas, 55, 78.
Pedal of piano, 45.
Pelvis of kidney, 119, 185.
Pendulum, 131.
Pepsin, 74, 75, 76, 180, 181.
Peptone, 75, 77, 181.
Pericardium, 84, 85, 86, 102, 119, 128; pericardial fluid, 85, 176: of rabbit, 173, 176; of sheep, 181; pericardial space, 85.
Perichondrium, 19, 47.
Perilymph, 154, 155, 156, 157.
Periosteum, 17, 18, 47.
Peristaltic action, 73, 74, 75.
Peritoneum, 56, 63, 102, 117; of rabbit, 172.
Perspiration, 121, 123, 124, 157.
Pharynx, 15, 60, 67, 73, 106, 149, 150, 153; of ox, 193; of rabbit, 175.
Phosphorus, 48, 51, 53, 54, 55; pentoxide, 51.
Physics, 8.
Physiology, 7, 8.
Pia mater, 128, 177.
Pig, 11, 181.
Pigment, 121, 159, 160, 163.
Pillars of diaphragm, 105, 172.
Pins, 170.
Pithing of frog, 185.
Plasma; blood, 81, 83, 84, 113; milk, 200.
Plants, 7, 53, 54.
Pleura (*pl.* pleuræ), 102, 106, 128; of rabbit, 174.
Plexus, 130.
Pluck of sheep, 181.
Poker, 44.
Pomatum, 121.
Pores of skin, 122.
Porridge, 79.
Potash; caustic, 200; chlorate of, 50.
Potassium ferrocyanide, 180, 181.
Potatoes, 78.
Power, 43; levers of power, 45.
Practical work, 8, chap. xi.
Premolar teeth, 58.
Preparation; of ammonia, 115; of carbon dioxide, 109; of hydrogen, 52; of nitrogen, 51; of oxygen, 50.
Pressure, 19, 22, 30, 33, 36, 38, 39, 121, 145, 147; sense, 147.
Process; acromial (acromion), 33; articular, 28; ciliary, 160, 164, 187; coronoid, 26, 71; odontoid, 29, 41; olecranon, 35; spinous (neural spine), 28; transverse, 28.
Pronation, 35, 41.
Protection, 13, 121.
Proteids, 54, 55, 56, 73, 77, 79, 82, 83, 84, 115, 124, 179, 180, 181, 197, 198.
Proteolytic, 75.
Protoplasm, 64, 83, 105, 124, 125, 203.

Proximal, 34.
Psalter, *see* Manyplies.
Ptyalin, 72, 73, 75, 180.
Pulp of teeth, 59, 145.
Pulse, 100, 183; air pulses, 152.
Pungent smells, 151.
Pupil, 159, 165, 166, 187, 188.
Putrid smells, 151.
Pyloric end of stomach, 61, 66, 74.
Pylorus, 67, 70; of ox, 194; of rabbit, 176.
Pyramids of kidney, 118, 185.

Quicklime, 108, 109.
Quinine, 187.

Rabbit, 8, 11, 17, 106, 137, 140; dissection of, 171–178.
Radiation, 124.
Rain, 108.
Ramus (*pl.* rami), 26, 72.
Rapidity, levers of, 45.
Rat, 183.
Razor, 170.
Reagents (chemical), 179, 189, 190.
Reception of food in ox, 195.
Rectum, 63; of ox, 194; of rabbit, 172.
Reduced hæmoglobin, 112, 113, 114.
Reduction, 112, 113.
Reflection, 163.
Reflex action, 134, 140, 142, 166, 185, 197, 204; acquired, 143; nerve centre, 141.
Refraction, 163.
Regions; of body, 9; of limbs, 10.
Renewal, 15.
Rennet, 181, 201.
Rennin, 74, 181, 201.
Repair, 18.
Respiration, 15, 51, chap. vi., 140, 184; movements of, 31, 105, 184; rate of, 106.
Respiratory centre, 140, 141.
Respiratory organs, 15, 16; chap. vi., 114.
Reticulum, *see* Honeycomb bag.
Retina, 160, 166, 167, 187, 191.
Rice, 78.
Ridges on fingers, 122.
Rods, *see* Cells, visual.
Root; of lung, 192; of spinal nerve, 130, 132, 133, 144.
Rugæ, 65.
Rumen, *see* Paunch.
Rumination, 193, 195, 196, 197.

Saccule, 157.
Sal-ammoniac, 116.
Saliva, 67, 71, 72, 73, 180; of ox, 195, 196, 197.
Salt, *see* Sodium chloride.
Saltpetre, 149.
Salts, mineral; of blood, 113; of milk, 200; of sweat, 123; of urine, 115, 120. *See also* Ash and Food, mineral.
Salt tastes, 149.
Sausage skins, 179.
Scalpel, 170.
Schmidt-Mülheim, 205.
Scissors, 170.
Sclerotic, 159, 187, 188.
Secretion, 65; of bile, 70, 75; of gastric juice, 66, 74; of intestinal juice, 65; of milk, 203, 204, 205; of pancreatic juice, 75; of saliva, 67, 68, 69, 72, 196.
Seeker, 170.
Sensation, 16, 132, 134, 140, 142, 143, chap. x.
Sense organs, 17, chap. x.; of rabbit, 178.
Sensible perspiration, 123.
Sensory centres, 142, 144.
Serous coat, 63.
Serum, 83, 84.
Shaft, 18, 19, 34, 37.
Sheath of muscle, 42, 47.
Sheep, 8, 11, 158, 181, 184, 196.
Shocks, breaking of, 19, 25, 27, 28, 33, 36, 39, 40.
Short sight, 168.
Shoulder, 10, 11, 34, 41.
Sight, 9, 17, 139, 144, 157–168, 187–188.
Sigmoid flexure, 62.
Skeleton, 13, 21; chap. ii., 169.
Skin, 14, 15, 16, 57, 64, 67; chap. viii., 130, 131, 134, 139.
Skull, 20, 22, 26, 28, 40, 44, 128.
Sleep, 143.
Slides, 188, 190.
Smell, 9, 17, 139, 144, 150–152, 157–168, 187.
Smelling salts, 115, 151.
Smells, 151.
Sneezing, 114, 140.
Sniffing, 151.
Soda-water, 48.
Sodium (Na), 55; carbonate, 181; chloride (NaCl), 55, 115, 123, 186, 187, 190, 204.
Sole of foot, 12, 121, 145.
Solution, 73, 75, 76, 77, 150, 179, 180, 187, 197.
Sound; of heart, 92; muscle, 92; waves, 153, 155.
Sour tastes, 149.
Spectacles, 168.
Sphincter; of bladder, 118; pyloric, 66, 74; of rectum, 65; of cow's teat, 203.
Spinal bulb (medulla oblongata), 135, 137, 141; of rabbit, 177.
Spinal cord, 11, 12, 13, 17, 127, 129, 130, 133, 134; of rabbit, 177.
Spinal marrow, *see* Spinal cord.
Spine, *see* Vertebral column; neural, 28, 29.
Spittle, *see* Saliva.

Spleen, 71, 94, 101, 172.
Spontaneous actions, 140.
Spring, vibrations of, 153.
Stability, levers of, 45.
Stage of microscope, 188, 189.
Stand of microscope, 188, 189.
Starch, 55, 72, 73, 75, 77, 179, 180, 197, 198.
Steam-engine, 47, 125.
Steapsin, 76.
Stethoscope, 92.
Stimulation, 132, 133, 145, 149, 151, 155, 161, 185, 186.
Stimulus (*pl.* stimuli), 132, 133, 134, 135, 140, 142, 144, 145, 149, 151, 152, 155, 161, 166, 185, 186, 187.
Stirrup (stapes), 154, 155.
Stomach, 15, 56, 60, 61, 62, 63, 65, 66, 67, 69, 71, 73, 74, 75, 77, 80, 94, 139, 194; of ox, 193, 194; of rabbit, 172, 176, 180.
Stroma, 82.
Structure, 7.
Stuffiness, 110.
Sub-arachnoid space, 128.
Subdural space, 128.
Submucous coat, 63.
Suffocation, 113.
Sugar, 55, 72, 73, 77, 149, 179, 180, 187, 197, 198; grape-, *see* Glucose; malt-, *see* Maltose; milk-, 200, 203, 205.
Sulphur (S), 48, 51, 53, 54, 55; dioxide, (SO_2), 51.
Supination, 35.
Support, 13.
Suture, 22.
Swallowing, 73, 103, 140.
Sweat, 121, 123, 124, 157.
Sweetbread, *see* Pancreas.
Sweet tastes, 149.
Symbols, chemical, 48.
Symmetry, 8, 9.
Sympathetic system, 17, 127, 142.
Synthesis, 108.
Syntonin, 55.
Systole, 90, 91, 183.

Taste, 17, 139, 144, 148, 150, 187; buds, 149.
Tastes, 149.
Tear, 25, 158; duct, 158; gland, 158; sac, 158.
Teats of cow, 201, 202, 203.
Teeth, 25, 55, 57, 58, 59, 71, 95, 139, 145 175; of ox, 192, 195, 196; of rabbit, 175.
Temperature; of blood, 123; of body, 15, 121, 123; of expired air, 110; sense, 147, 186.
Temples, 23, 72.
Tendon, 42, 47, 72, 177; of Achilles, 44; of diaphragm, 105.
Thigh, 10, 147.
Thirst, 144.
Thorax, 10, 12, 15, 16, 20, 31, 33, 60, 84, 91, 92, 93, 101, 102, 106; of rabbit, 173, 174, 184.
Thumb, 11, 36, 41.
Throat, 12, 15, 16; sore, 152.
Thyroid cartilage, 102.
Tickling, 134.
Tissue, 17, 47, 80, 126; connective, 17, 19, 42, 47, 55, 59, 63, 69, 96, 104, 106, 112, 123, 128, 170, 201; subcutaneous, 122, 123. *See also* Blood, Epithelium, Muscle, and Nerve.
Toes, 11, 22, 39, 44, 45, 121, 122.
Tongue, 26, 57, 68, 71, 73, 139, 145, 147, 150, 175; of ox, 192; of rabbit, 175.
Tonic condition of muscles, 46, 100.
Tonsil, 60.
Touch, 17, 121, 144, 145–148, 186.
Trachea, 16, 74, 102, 103, 113, 114, 151; of rabbit, 174, 177, 184.
Treacle, 76.
Trunk, 10, 11, 20, 130; of spinal nerve, 130.
Tubules; of milk gland, 201, 202; of sweat gland, 122; uriniferous, 119, 120, 185.

Udder of cow, 201, 204.
Unconsciousness, 143. *See* Fainting.
Upright position, 46.
Urea, 114, 115, 120, 123, 185.
Ureter, 16, 118, 119; of rabbit, 173; of sheep, 184.
Urethra, 118.
Urinary organs, 16, chap. vii.
Urine, 115, 118, 119, 120, 123, 126, 185.
Utricle, 157.
Uvula, 57, 175.

Valve; Eustachian, 88, 182; ileocæcal, 65; mitral (bicuspid), 90, 91, 92, 182; semilunar, (watch-pocket), 90, 91, 92, 96, 112, 114, 182; Thebesian, 88, 182; tricuspid, 89, 91, 92, 182; of veins, 96.
Vapour, 151.
Vegetable diet, 79.
Vein, 80, 87, 88, 94, 95, 96, 97, 98, 100; inferior vena cava, 88, 93, 120, 173, 182; superior vena cava, 88, 93, 176, 182; coronary, 94; coronary sinus, 88, 93, 94, 182; hepatic, 94; jugular, 97, 176; portal, 94, 95, 173; pulmonary, 88, 90, 93, 112, 176, 182; of rabbit, 172, 173, 176; renal, 120; of sheep, 182, 183; subclavian, 176.
Ventilation, 110, 111, 204.
Ventral, 9.
Ventricles; of brain, 136, 138, 140, 178; of heart, 86, 87, 88, 89, 90, 92, 100, 181, 182, 183.
Vermiform appendix, 62; of ox, 194; of rabbit, 172.

Vertebral column, 12, 20, 26, 31, 60, 117, 128.
Villus (*pl.* villi), 63, 65, 77, 176, 191.
Vibrations; of air, 152; molecular, 131; 144, 150, 151, 155, 167; of sounding bodies, 152, 153.
Vitriol, oil of, *see* Acid, sulphuric.
Voluntary actions, 140, 143.

Warmth, 144.
Waste products, 14, 15, 16, 83, 94, 113, 114, chap. vii., 125.
Watchmaker's eye-glass, 170.
Water, 48, 49, 52, 53, 54, 55, 56, 72, 75, 76, 79, 101, 109, 111, 114, 115, 120, 123, 124, 198, 200, 203, 204; vapour, 110, 184.
Web of frog's foot, 184.
Weight, 43.
Wheat-flour, 78.
Whipped blood, 84.
White; of egg, 55, 179, 180; of the eye, 159; matter of brain, 136, 138, 178; of spinal cord, 129.
Wide albuminoid ratio, 199.
Will, 17, 73, 134, 140, 142.
Windpipe, *see* Trachea.
Wisdom teeth, 59.
Wolff, 198, 199.
Woody fibre, 198.
Work, 92, 125, 126.
Wrist, 10, 20.
Wrong way, going the, 74.

Xanthoproteic reaction, 179, 180.

Yellow spot, 160, 166, 187.

Zinc, 52.
Zoology, 7, 8.
Zymine peptonizing powder, 181.

APPENDIX.

EXTRACT FROM THE DIRECTORY OF THE SCIENCE AND ART DEPARTMENT.

SYLLABUS OF REQUIREMENTS IN HUMAN PHYSIOLOGY.

FIRST STAGE OR ELEMENTARY COURSE.

Questions will be confined to the under-mentioned points in the elements of anatomy and physiology.

Candidates are expected to have seen the corpuscles of the blood under a microscope, magnifying about three or four hundred diameters. It is also desirable that they should have made themselves acquainted in like manner with the general microscopic characters of the cells constituting epithelium. Other details of structure needing the use of a microscope will not be asked for.

The information demanded under "Chemical Preliminaries" is limited on the one hand to elementary and fundamental chemical principles as applied to the animal body, and on the other to the important properties of the chief chemical substances composing the body and food. In respect to these points the answers must be precise, but no further chemical knowledge will be required.

No candidate will be allowed to pass who in the answers makes gross errors concerning the general build of the body and the relations of its several parts, the structure and working of the heart and the main facts of the circulation, the mechanical and chemical changes of respiration, the chemical nature of food, its changes in the alimentary canal, and its use in the body.

A. Anatomical Preliminaries.

The general build of the body.

The form, the position, and the uses of the following parts of the skeleton:—skull, vertebræ, ribs, sternum; scapula, clavicle, humerus, radius, ulna, carpus, metacarpus, phalanges (of the hand); pelvis, femur, tibia, fibula, tarsus, metatarsus, phalanges (of the foot).

The more obvious distinctive characters of skin, mucous membrane, glands, connective tissue, tendon, ligament, cartilage, bone, muscle, and nerve.

The position in the body, and the general form and size, of the following internal organs:—The brain and spinal cord; the pharynx, gullet, stomach, and intestines; the salivary glands, the liver, and the pancreas; the posterior nares, the larynx, trachea, and lungs; the diaphragm; the kidneys and the bladder; the heart and the great vessels; the spleen.

B. Chemical Preliminaries.

The simpler chemical properties of carbon, oxygen, hydrogen, and nitrogen; the meaning of the terms "element", "compound", "decomposition", "oxidation", as illustrating elementary chemical principles.

The composition, nature, and properties of air, water, carbon dioxide (carbonic acid), and ammonia.

The chemical elements of which proteids, fats, and carbohydrates are composed; the general chemical properties of these substances, and the relative proportions in which the several elements are present in each of them.

The composition and general nature of urea.

C. General View of the Animal Body in Action.

The movements of the body as the result of muscular action.

Muscular action viewed as chemical change (oxidation) of the muscle, whereby energy is set free, and waste of substance caused.

The blood as the agent which (*a*) removes the waste, and (*b*) supplies fresh nutritive material to make good the waste.

The waste matter in the blood got rid of by the excretory organs. The fresh nutritive material in the blood supplied to it from food by means of the digestive organs.

The control of the muscles by the nervous system, consisting of (*a*) sensory or afferent nerves, (*b*) the brain and spinal cord, (*c*) motor or efferent nerves.

The general functions of the brain and spinal cord.

The maintenance of the erect posture.

Local and general death.

D. Special Physiology.

a. The Blood.—The form, size, and structure of the corpuscles of the blood.

The general composition of the blood.

The phenomena presented by blood drawn from the body; clotting of blood.

b. The Circulatory System.—The general structure of the heart; the form and arrangement of its chambers; the nature of its walls; the form and position of its valves. The differences between the right and left side of the heart.

The action of the heart as a force-pump.

The mode and action of the valves during the heart-beat.

The general difference between arteries, capillaries, and veins.

The course of the circulation and the reason why the blood moves in only one direction.

The characters of and differences in the blood-flow in arteries, capillaries, and veins.

The meaning of the "pulse".

The evidence of the circulation obtainable in the living body.

c. THE ALIMENTARY SYSTEM.—The general form and arrangement of the alimentary canal in its several parts.

The more obvious characters of the mucous coat, and the differences in respect to it between the stomach and the small and large intestine.

The relationship of the salivary and gastric glands, and of the pancreas and liver, to the alimentary canal. The character and uses of their secretions.

The general nature of food. The classification of food-stuffs. The changes the several food-stuffs respectively undergo in the alimentary canal, and how these are brought about.

The manner in which nutritive matters are absorbed and innutritious matters got rid of from the alimentary canal.

The economy of a mixed diet.

d. THE LIVER.—Position and general structure of the liver. The blood supply to the liver.

The obvious characters and properties of bile.

e. THE RESPIRATORY SYSTEM.—The arrangement of the ribs, sternum, intercostal muscles, and diaphragm. The manner in which the walls and floor of the chest change their position during the respiratory movements.

Why air enters and leaves the chest during inspiration and expiration respectively.

The course taken by the air when breathing through the nose.

In what respects the air which leaves the lungs differs from that which enters them.

The obvious differences between venous and arterial blood. Where and how venous blood is converted into arterial, and arterial into venous blood in the body. How venous blood can be converted into arterial blood out of the body.

The conditions which give rise to asphyxia.

f. THE URINARY SYSTEM.—The structure of the kidney so far as it is visible to the naked eye.

The composition of urine as far as its chief constituents are concerned; the significance of these as waste products.

g. THE SKIN.—The obvious differences between the dermis and epidermis.

The general composition of sweat.

The more obvious functions of the skin.

h. ANIMAL HEAT.—The sources of the heat of the body. The manner in which heat is distributed through the body, and in which the temperature of the body is regulated.

i. THE MUSCULAR SYSTEM AND ANIMAL MECHANICS.—The structure of muscle, of tendon, and of bone, so far as it can be made out by the naked eye or a simple lens. The mode of attachment of muscles to bones.

The nature of joints, with examples of ball-and-socket, hinge, and pivot joints.

The different kinds of levers, with examples of them in the body.

The way in which muscles lead to the movements of the body.

k. THE SENSES.—The different kinds of sensations.

The means of measuring the acuteness of the sense of touch in various parts of the body.

The general structure of the organs of smell and taste, and the manner in which their functions are performed.

The general structural arrangements of the eye-ball. Such characters of the cornea, sclerotic, choroid, iris, aqueous and vitreous humours, crystalline lens and retina as can be observed by ordinary dissection. The uses of the cornea, iris, and crystalline lens.

How the pupil is enlarged and made narrower, and for what purposes.

The change undergone by the lens when looking from a distant to a near object; the object of this change.

The blind spot, and what it teaches.

The essential facts as to the structural arrangements of the ear so far as they are required to explain how sound-waves are conveyed to the nerves of hearing.

l. THE NERVOUS SYSTEM.—The chief parts into which the brain may be divided.

The structure of the spinal cord so far as it is visible to the naked eye. The arrangement and the functions of the roots of the spinal nerves.

The general way in which the spinal cord is connected to the brain by means of the spinal bulb or medulla oblongata.

The evidence that the spinal cord is capable of effecting reflex action.

The general phenomena presented by an animal deprived of its brain, as illustrating some of the more important functions of the brain.

EXAMINATION PAPERS IN HUMAN PHYSIOLOGY.

General Instructions.

Put the number of the question before your answer.

The value attached to each question is shown in brackets after the question, but a full and correct answer to an easy question will in all cases secure a larger number of marks than an incomplete or inexact answer to a more difficult one.

Your name is not given to the Examiners, and you are forbidden to write to them about your answers.

You are to confine your answers *strictly* to the questions proposed.

The examination in this subject lasts for three hours.

MAY, 1894.

First Stage or Elementary Examination.

Instructions.

You are permitted to attempt only *eight* questions.

1. Where and how is the diaphragm placed in the body? What organs lie immediately above and what immediately below it? What structures pass through it? How does the diaphragm work in breathing, and what makes it work? (15.)

2. How would you place a heart in front of yourself so as to see the left auricle most easily? What does the left auricle look like as seen from the outside, and what does its inside look like when laid open? What blood-vessels enter the left auricle, and how is it connected with the left ventricle? (15.)

3. What is the general shape and appearance of the stomach? What is its general structure? In what way does the internal lining of the stomach differ from that of the small intestine? What changes does proteid food undergo in the stomach? (15.)

4. How can you tell the difference between a large artery and a vein of the same size as *seen* by dissection in a dead body? What further differences are there between an artery and a vein besides those you can make out by mere dissection? What are the special uses of these differences? (15.)

5. What are lacteals, and where do they occur? What is in them when an animal is fasting, and what is in them after a meal of mixed food? How are their contents finally passed into the blood? (10.)

6. How can you show that there is a "blind spot" in each of your own eyes? What does the blind spot teach us as to the nature of sight? (10.)

7. What movements can you make with your hand at the wrist joint? How do the movements you can make with your foot at the ankle joint differ from those you can make with your hand at the wrist? What are the differences in the joints which cause the difference in the movements? (10.)

8. What do you understand by a "reflex action"? What structures are essential for the occurrence of a reflex action? Give two or three examples of reflex action as it may be observed in your own body? What is the use of reflex actions? (10.)

9. Of what two parts is the skin composed? What are the more obvious and important differences between these two parts? What are the chief uses of the skin to the body? (10.)

10. What are the various causes or conditions which make a person breathe faster than usual? What is the exact cause and what is the real use in each case of the faster breathing? (10.)

11. What is the spinal bulb or medulla oblongata, and where is it placed in the body? What is its form and general appearance? What are its more important uses? (10.)

12. What part of the nose is used for smelling? What nerve is used for smelling? With what part of the brain is this nerve connected, and how does it pass from the brain to the nose? Why cannot you either smell or taste properly when you have a bad cold in your head? (10.)

MAY, 1895.

(*Instructions as in 1894.*)

1. What structures form the walls of the thorax or chest? What organs lie inside the thorax? What movements do the walls make during inspiration, and what movements do they make during expiration? How are these movements produced? (15.)

2. What differences of structure are there between the right and left ventricle of a heart? To what differences in action do these differences correspond? What is the form and structure of the valve between the left auricle and left ventricle, and how does this valve work so as to carry on the circulation of the blood? (15.)

3. Where and how is the spinal cord placed in the body? How does it end above and how does it end below? What structures are given off at repeated intervals from the spinal cord, and what are the uses of these structures? (15.)

4. What are the essential differences between fats and carbohydrates? Where and how are fats digested, where and how are carbohydrates digested in the body? (15.)

5. Describe the position and general structure of the liver. What is there peculiar about the blood-supply to the liver? What is the most obvious use of the liver, and what are the arrangements by which that use is carried out? (10.)

6. What changes can be *seen* to take place in blood after it is drawn off from the body and kept for some time? What has taken place *in* the blood to cause these changes which you can see? (10.)

7. Describe how the skull is attached to the spinal column or backbone, and explain how this attachment enables you to (i) nod your head up and down; (ii) turn your head from side to side. (10.)

8. What is the structure of a muscle and its tendon so far as these can be made out by careful dissection, without having recourse to a microscope? How are the muscles usually placed and attached to the bones so as to lead to the movements of the body? (10.)

9. Of what substances is sweat chiefly composed? By what organs other than the skin are some of the constituents of sweat also got rid of from the body? How does it come about that perspiration is usually "insensible", and what has happened when it becomes "sensible"? (10.)

10. If you cut through a *large* clot of blood or piece of lean meat, the inside is of a much darker colour than the outside. Explain why there is this difference of colour. What important facts do you learn from the above observation? (10.)

11. What is the pupil of the eye? When and by what means does it become smaller, and when does it become larger? What are the uses of the pupil becoming smaller and larger? (10.)

12. If you keep your leg or arm too long in a bent position it often "goes to sleep". What has happened in your leg or arm when it has thus "gone to sleep". and why is it nearly useless to you while in this condition? (10.)

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